A

TREATISE

ON

MAGNETISM,

FORMING THE ARTICLE UNDER THAT HEAD IN
THE SEVENTH EDITION OF THE

ENCYCLOPÆDIA BRITANNICA

BY

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PREFACE.

In drawing up the following Treatise for the Encyclopædia Britannica, I have endeavoured to give a popular account of the science of Magnetism, and have therefore omitted all abstruse and theoretical discussions of a mathematical nature. The progress of inquiry in this department of Physics has been so rapid, and many of the most important discoveries have been so recently made, that it has been labour of no ordinary kind to collect their details from the various periodical works in which they have been published. I have therefore been led to give a pretty full account of the discoveries and researches of Arago, Barlow, Becquerel, Biot, Christie, Coulomb, Dalton, Duperney, Erman, Faraday, Gauss, Haldat, Hansteen, Snow Harris, Herschel and Babbage, Humboldt, Kater, Kupffer, Pouillet, Quetelet, Scoresby, and Seebeck.

The interesting subject of Terrestrial Magnetism, which has been so much advanced by the British

and French expeditions of discovery, by the journey to Siberia, undertaken by Professor Hansteen, has been treated at considerable length; and, through the kindness of Professor Barlow, I have the satisfaction of illustrating this part of the subject with his valuable chart of the magnetic curves, containing the recent observations of Commander Ross, by which the position of the north-west magnetic pole has been so accurately ascertained.

D. B.

ALLERLY, *March* 21, 1837

CONTENTS

Page

CHAPTER I.

On the History of Magnetical Discoveries, 3

CHAPTER II.

On the General Phenomena and Properties of Magnetic Bodies, 68

Sect. I. On the Attractive Power of Magnetic Bodies upon Soft Iron, 69

Sect. II. On the Attractive and Repulsive Power of Magnets over each other, or over Iron either Temporarily or Permanently Magnetised, 71

Sect. III. On the Effect of Masses of Iron on the Attractive Force of a Magnet, 72

Sect. IV. On the Polarity of Magnetic Bodies, ib.

Sect. V. On the Power of Magnets to communicate Magnetism to other Bodies, 75

Sect. VI. On the Distribution of Magnetism in Artificial Magnets, 80

Sect. VII. On the Effect of Division and Fracture in the Distribution of Magnetism, 86

Sect. VIII. On Magnetic Figures, 89

CHAPTER III.

On the Magnetism of Bodies not Ferruginous, 94

Sect. I. On the Magnetism of Metals, Minerals, and other Bodies, ib.

Sect. II. Account of the Experiments of Coulomb, Becquerel, Arago, and Seebeck, on the Existence of Universal Magnetism, 101

Page

CHAPTER IV.

ON THE DEVELOPMENT OF MAGNETISM IN ALL BODIES BY ROTATION, 112

CHAPTER V.

ON THE INFLUENCE OF HEAT ON MAGNETISM, . . 127
SECT. I. On the Effect of Heat on the Development of Magnetism in Cast and Malleable Iron, . . ib.
SECT. II. On the Anomalous Attraction observed in Cast and Malleable Iron during the Bright Red and Red Heats, 129
SECT. III. On the Effects of Heat on the Distribution of Magnetism on Magnets, . . 133

CHAPTER VI.

ON THE ACTION OF SIMPLE IRON BODIES ON THE MAGNETIC NEEDLE, 143
SECT. I. On the Action of Spheres and Spherical Shells of Iron on the Magnetic Needle, ... ib.
SECT. II. On the Action of Simple Iron Bars and Plates on the Magnetic Needle, ... 149
SECT. III. On the Action of Irregular Masses of Iron on the Magnetic Needle, ... 151

CHAPTER VII.

ON THE INFLUENCE OF MAGNETISM ON CHEMICAL ACTION, . 153

CHAPTER VIII.

ON THE LAWS OF THE MAGNETIC FORCES, THE MUTUAL ACTION OF MAGNETS, AND MAGNETIC CURVES, ... 158
SECT. I. On the Law of the Magnetic Force, . . ib.
SECT. II. On the Mutual Action of Magnets, . . 165
SECT. III. On Magnetic Curves, . . . 171

CHAPTER IX.

ON TERRESTRIAL MAGNETISM, ... 183
SECT. I. On the Variation of the Needle, . . 184
SECT. II. On the Dip or Inclination of the Needle, . 233
SECT. III. On the Intensity of Terrestrial Magnetism, . 245
SECT. IV. On the Nature and Causes of the Earth's Magnetism, 261

CHAPTER X.

ACCOUNT OF THE DIFFERENT METHODS OF MAKING ARTIFICIAL MAGNETS, ... 281

CONTENTS.

	Page
SECT. I. Account of Dr Godwin Knight's method of making Artificial Magnets,	282
SECT. II. Account of Duhamel's method,	283
SECT. III. Account of Mr Michell's method,	285
SECT. IV. Account of Canton's method,	286
SECT. V. Account of Æpinus's method,	289
SECT. VI. Account of Coulomb's method,	290
SECT. VII. Account of M. Biot's method,	293
SECT. VIII. Account of Mr Scoresby's method,	294
SECT. IX. Method of making Horse-Shoe Magnets,	298
SECT. X. Account of Professor Barlow's method of magnetizing a number of Rectilineal Bars with a Horse-Shoe Magnet,	301
SECT. XI. Account of Knight's method of forming Artificial Magnets with an Iron Paste,	ib.
SECT. XII. Account of the method of arming and preserving Natural and Artificial Magnets,	304
SECT. XIII. Account of the method of making Temporary Bar Magnets of Soft Iron under the Influence of Electric Currents,	307
SECT. XIV. Account of M. Aimé's method of making Permanent Artificial Magnets,	313
SECT. XV. Account of the Experiments made by Coulomb and Kater, on the efficacy of the different methods of making Artificial Magnets,	314

CHAPTER XI.

DESCRIPTION OF MAGNETICAL INSTRUMENTS,	319
SECT. I. On the best Form and Construction of Compass Needles,	ib.
SECT. II. Description of the Common and Azimuth Compass,	323
SECT. III. Account of Captain Kater's Azimuth Compass,	325
SECT. IV. Account of the Variation Compass,	328
SECT. V. Description of Colonel Beaufoy's Variation Transit,	329
SECT. VI. Account of Dollond's Variation Transit,	332
SECT. VII. Description of Dollond's Diurnal Variation Instrument,	333
SECT. VIII. Description of the Dipping Needle as constructed by Messrs Gilberts,	334
SECT. IX. Account of Mr Scoresby's Magnetometer for measuring the Dip of the Needle,	337
SECT. X. Account of Daniel Bernoulli's Dipping Needle,	338

Page

SECT. XI. Account of Mayer's Dipping Needle as constructed for Captain Sabine, ... 340

SECT. XII. Account of Professor Lloyd's method of observing the Dip and the Magnetic Intensity at the same time, and with the same Instrument, ... 342

SECT. XIII. Description of Mr Fox's Dipping Needle Deflector, for measuring the Variation and Dip of the Needle, and the Magnetic Intensity, ... 344

SECT. XIV. Account of Lebaillif's Sideroscope, . 352

SECT. XV. Description of the Astatic Needle, . . 353

SECT. XVI. Account of Barlow's Correcting Plate or Magnetic Compensator, for neutralizing the effect of Local Attraction on the Ship's Compass, ... 355

CHAPTER XII.

THEORIES OF MAGNETISM, ... 360

TREATISE

ON

MAGNETISM.

The word magnetism is derived from the Greek word μαγνης, a name given to the *loadstone* or *native magnet*, an ore of iron well known to the ancients. The term μαγνης itself is said to be derived from one *Magnes*, a Greek shepherd, who observed on Mount Ida the attractive power which the loadstone exercised upon his iron crook. The most probable supposition, however, is, that it took its name from *Magnesia*, a country in Lydia, where it was first discovered; and this conjecture is confirmed by the fact, that the magnet was often called by the ancients *Lapis Heracleus*, from *Heraclea*, the capital of *Magnesia*.

The science of magnetism treats of the phenomena exhibited by magnets, whether natural, like the loadstone, or artificial, like bars of steel to which magnetism has been permanently communicated; of their reciprocal action upon each other; of the laws of the forces which they develop; of the methods of making artificial magnets; and of the magnetic phenomena exhibited by the globe which we inhabit.

In giving an account of this interesting science, which has made rapid progress in modern times, we shall adopt the following arrangement:

1. On the history of magnetical discovery.
2. On the general phenomena and principles of natural and artificial magnets.
3. On the magnetism of bodies not ferruginous.
4. On the development of magnetism in bodies by rotation.
5. On the influence of heat on magnetism.
6. On the action of iron spheres on the needle.
7. On the influence of magnetism on chemical action.
8. On the laws of magnetic forces.
9. On terrestrial magnetism.
10. On the different methods of making artificial magnets.
11. On magnetical instruments and apparatus.
12. On the theories of magnetism.

CHAPTER I.

ON THE HISTORY OF MAGNETICAL DISCOVERIES.

THE attractive power of the natural magnet or loadstone over small pieces of iron seems to have been known from the remotest antiquity. It is distinctly referred to by Homer, Pythagoras, and Aristotle. Pliny mentions a chain of iron rings suspended from one another, the first being upheld by the loadstone; and he relates that Dinocares proposed to Ptolemy Philadelphus to build, at Alexandria, a temple, the vault of which, crowned with loadstones, should suspend in the air an iron statue of Queen Arsinöe. St Augustin likewise makes mention of a statue suspended in the air in the middle of the temple of Serapis at Alexandria. From references made to the magnet by Euripides, Claudian, and others, and from the experiment with the rings mentioned by Pliny,* it is not very improbable that the ancients were acquainted with the communicability of magnetism to iron bodies. The magnetical properties of the loadstone, like the electrical ones of amber, were supposed to be miraculous. Medical qualities of various kinds were ascribed to it; and even Hippocrates ranks it amongst the number of purgatives.

In order to explain the properties of the loadstone, Thales, Anaxagoras, and others, supposed it to have a soul; while some conceived that it was surrounded with an emanation, capable of creating a vacuum, into which the iron precipitated itself.

In his description of China, Duhalde has stated, that

* Sola haec materia (ferrum) vires ab eo lapide accipit, retinetque longo tempore, aliud apprehendens ferrum, ut annulorum catena spectetur interdum, quod imperitum vulgus ferrum appellat vivum.

the directive power, or polarity of the magnet, was known to the Chinese in the earliest ages, and that the needle had been employed to guide travellers by land a thousand years before Christ; and it is stated by Humboldt, that, according to the *Peuthsaoyani*, a treatise on Medical Natural History, written under the Saong dynasty, four hundred years before Columbus, the Chinese suspended the needle by a thread, and found it to decline to the south-east, and never to rest at the true south point.

Although the common properties of the loadstone were known to the ancients, and were no doubt studied even during the dark ages, yet, notwithstanding the claims of the Chinese and Arabians, the directive power of the loadstone, or of a needle touched or rubbed by it, seems to be the discovery of modern times. Are Frode, an Icelandic historian, who was born in the year 1068, and who must have written his *Landnamabok*, or history of the discovery of Iceland, about the end of the eleventh century, mentions, in the most unequivocal manner, the directive power of the loadstone as known in his day. He states that Floke Vilgerderson, a renowned viking or pirate, departed from Rogoland in Norway, to seek Gadersholm or Iceland, some time in the year 868. He carried with him three ravens as guides, and, to consecrate them for this purpose, he offered up a sacrifice in Smörsund, where his ship lay. "*For*," says Frode, "*in those times seamen had no loadstone** *in the northern countries.*"

That the mariner's compass was known in the twelfth century, about the year 1150, is proved by notices of it in various authors, particularly in an old French poem called *La Bible Guyot*, which is contained in a curious quarto manuscript of the thirteenth century, still existing in the Royal Library at Paris. Guyot of Provins, the author of this poem, was alive in 1181. After referring

* *Leidarstein*, or *Leading Stone*, from which our word *Loadstone* is derived.

to the ways by which navigators are guided in their course, and mentioning the pole-star, he adds,—

Un art font qui mentir ne peut,
Par la vertue de la marinière,
Un pierre laide et brunière
Où le fers volontiers se joint,
Ont regardent lor droit point.

That is, "They possess a never-failing method, by the virtue of the marinière, an ugly and brown stone, to which iron adheres of its own accord." The author next adds, that this art consists in rubbing a needle on the *marinière;* and that the point of this needle turns just against the pole-star in dark nights, when neither star nor moon is seen.

Quant il nuit est ténèbre et brune,
Quand ne voit estoile ne lune,
Lor font à l'aiguille allumer,
Puiz ne peut ils assorer,
Contre l'estoile va le pointe,
Par se sont il mariner cointe,
De la droit voie tems :
C'est un art qui ne peut mentir.

Cardinal James de Vitri, who flourished about the year 1200, mentions the magnetic needle in his History of Jerusalem; and he adds, that it was of indispensable utility to those who travelled by sea.

That the mariner's compass was known to the northern nations in 1266, appears from Torfæus's History of Norway, where it is mentioned that Jarl Sturla's poem on the death of the Swedish count Byrgeres was rewarded with a mariner's compass. The directive property of the magnet is also distinctly mentioned in an epistle of Petrus Peregrinus de Marcourt, written about the latter end of the thirteenth century. This letter was addressed "Ad Sigerium de Foueancourt militem de magnete." This epistle contains a description of the loadstone, the means of finding its poles, and its property of attracting iron;

and it proves that *the part of the magnet which is turned to the north attracts that which is turned to the south.*

A Neapolitan named Flavio Gioia, who lived in the thirteenth century, has been regarded by many as the inventor of the compass. Dr Gilbert affirms, that Paulus Venetus brought the compass from China to Italy in 1260. Ludi Vestomannus asserts, that about 1500, he saw a pilot in the East Indies direct his course by a magnetic needle like those now in use. One of the earliest treatises on magnetism is a Latin letter of Peter Adsiger, contained in a volume of manuscripts in the library of the university of Leyden. This letter, which appears to have been written for the instruction of a friend, is in reality a methodical treatise, in two parts, the first of which is subdivided into ten, and the second into three chapters. In the second chapter of the second part, the mariner's compass, and the method of constructing it, are clearly described; and what is still more interesting, the author not only mentions the declination of the magnetic needle, but had observed its actual deviation from the meridian. "Take notice," says he, "that the magnet, as well as the needle which has been touched by it, does not point exactly to the poles; but that part of it which is reckoned to point to the south, inclines a little to the west, and that part which looks towards the north, inclines as much to the east. The exact quantity of this declination, I have found, after numerous experiments, to be *five degrees*. However, this declination is no obstacle to our guidance, because we make the needle itself decline from the true south by nearly one point and a half towards the west. A point, then, contains five degrees." Mr Christie seems to consider the authenticity of this manuscript as doubtful, because no new observation of the declination seems to have been made for two centuries afterwards; and because the declination should be westerly in place of easterly in 1269, according to the

best law of the change which can be deduced from subsequent observations.

The declination or the variation of the needle, thus distinctly described by Adsiger, if his manuscript is authentic, must be considered as well known before the time of Columbus, to whom the discovery of it has been generally ascribed. His son Ferdinand states, that on the 14th of September, (13th according to Mr Irving,) 1492, his father, when about two hundred leagues from the island of Ferro, noticed for the first time the variation of the needle, — "a phenomenon," says Washington Irving, "which had never before been remarked." "He perceived," adds this author, "about nightfall, that the needle, instead of pointing to the north star, varied but half a point, or between five and six degrees to the north-west, and still more on the following morning. Struck with this circumstance, he observed it attentively for three days, and found that the variation increased as he advanced. He at first made no mention of this phenomenon, knowing how ready his people were to take alarm ; but it soon attracted the attention of the pilots, and filled them with consternation. It seemed as if the laws of nature were changing as they advanced, and that they were entering another world, subject to unknown influences. They apprehended that the compass was about to lose its mysterious virtues ; and, without this guide, what was to become of them in a vast and trackless ocean ? Columbus tasked his science and ingenuity for reasons with which to allay their terrors. He told them that the direction of the needle was not to the polar star, but to some fixed and invisible point. The variation was not caused by any failing in the compass, which, like the other heavenly bodies, had its changes and revolutions, and every day described a circle round the pole. The high opinion that the pilots entertained of Columbus as a profound astronomer gave weight to his theory, and their alarm

subsided."* Although the details which we have already given afford sufficient proof that the variation of the needle had been discovered two hundred years before the time of Columbus, yet it is evident, from the above passage, that he had discovered the variation of the variation, or that the variation was not a constant quantity, but varied in different latitudes.

Notwithstanding these casual observations on the variation of the compass, no accurate measures of its amount were made till about the middle of the 16th century. In 1541 it was found that the declination of the needle from the meridian of Paris was about 7° or 8° easterly. In 1550 it was 8° or 9°, and in 1580 11½° easterly. Norman,† who first observed the variation in London, made it 11° 15′ easterly; and Mr Burough,‡ comptroller of the navy, in 1580 found it to be at an average 11° 19′ E. at Limehouse. The following observations made at other places will show the gradual change in the variation.

Burough	1580	11°	19′	E.	Limehouse.
Gunter	1612	5	36	E.	London.
Gellibrand §	1633	4	4	E.	London.
Petit	1630	4	30	E.	Paris.
Petit	1660	0	10	E.	Paris.
Auzout	1670	2	0	W.	Rome.
Hevelius	1642	3	5	W.	Dantzig.
Hevelius	1670	7	20	W.	Dantzig.

The important discovery of the *dip*, or inclination of the needle, was made in 1576, by Robert Norman, whom we have already mentioned. Having constructed many com-

* Irving's *Life and Voyages of Columbus*, vol. i. p. 201.

† *The New Attractive*, by Robert Norman. Lond. 1596.

‡ *A Discourse on the Variation of the Compass.* Lond. 1581.

§ *Discourse Mathematical on the Variation of the Magnetical Needle*, 1635. Gellibrand found that the north-east of the needle was gradually moving to the westward.

passes, and having always balanced the needles for them before he touched them with the magnet, he invariably found, that after they were touched, the north point always inclined below the horizon, so that he was obliged to make the card of the compass level, by putting some small pieces of wire on the end of it. Having mentioned this discovery to some of his friends, he was advised to construct an instrument which would enable him to measure the greatest angle which it would make with the horizon. With this instrument, which is the dipping needle in its first and rudest form, he found the dip to be at $71^\circ 50'$; an observation which, according to Bond, must have been made about 1576.

That ferruginous substances always possess a greater or a less degree of magnetism, has been long known. One Julius Cæsar, a surgeon of Rimini, first observed the conversion of iron into a magnet. In 1590 he noticed this effect on a bar of iron which had supported a piece of brick-work on the top of a tower of the church of St Augustin. The very same fact was observed about 1630, by Gassendi, on the cross of the church of St John at Aix, which had fallen down in consequence of having been struck with lightning. He found the foot of it wasted with rust, and possessing all the properties of a loadstone.

While magnetism was making slow advances by means of insulated observations, it was destined to receive a vigorous impulse from the pen of Dr Gilbert of Colchester. This eminent individual, who was physician in ordinary to Queen Elizabeth, published, in 1600, his *Physiologia Nova, seu Tractatus de Magnete et Corporibus Magneticis*, a work which contains almost all the information concerning magnetism which was known during the two following centuries. It relates chiefly to the natural loadstone, and to artificial magnets, or bars of steel which have acquired similar properties. He applies the term magnetic to all bodies which are acted upon by loadstones

and magnets, in the same manner as they act upon each other, and he finds that all such bodies contain iron in some state or other. He considers the phenomena of electricity as having a considerable resemblance to those of magnetism, though he points out the differences by which the two classes of phenomena are marked. In treating of the directive power of the needle, he supposed, "that the earth itself being in all its parts magnetical, and the water not, wherever the land was, there would the needle turn, as to the greater quantity of magnetical matter." He regarded the earth as acting upon a magnetized bar, and upon iron, like a magnet, the directive power of the needle being produced by the action of magnetism of a contrary kind to that which exists at the extremity of the needle directed towards the pole of the globe. He gave the name of *pole* to the extremities of the needle which pointed towards the poles of the earth, conformably to his views of terrestrial magnetism, calling the extremity that pointed towards the *north* the *south pole* of the needle, and that which pointed to the *south* the *north pole*.

About the year 1650, Mr Bond, a teacher of mathematics in London, who had been employed to superintend the publication of the popular treatises on navigation, published a work called the *Seaman's Calendar*, in which he maintains that he has discovered the true progress of the deviation of the compass; and in another book, called *The Longitude Found*, and in the *Phil. Trans.* 1668, he published a table of the computed variations for London for many years to come, extending from 1663 to 1716. The results which this table contains agree very nearly with those which were observed for the next twenty-five years, but after that the differences became very great. In a subsequent paper in the *Phil. Trans.* for 1673, Bond attempted to account for the change in the variation and dip of the needle, by supposing *that the two magnetic poles*

revolved round the poles of the earth. He asserted that he knew the period of this revolution, as well as its cause; and he proposed to determine the longitude by means of the dip of the needle. He did not, however, think proper to communicate either his views or method to the public.

Newton, Huygens, Hooke, and some of the other philosophers who flourished about the end of the seventeenth century, were occupied, though not to a great degree, with the subject of magnetism. Some of their observations and discoveries are referred to in a manuscript volume of notes and commentaries, written by David Gregory in 1693, in a copy of Newton's *Principia*, and used by Newton in improving the second edition. Newton had supposed that the law of magnetic action approaches to the inverse triplicate ratio of the distance; but Gregory did not adopt this opinion, and invalidates the arguments which were used in its support. Newton committed another mistake in asserting, as we shall afterwards see, that red-hot iron has no magnetic property.

Several interesting experiments had been made by Dr Gilbert, on the effects of heat in destroying magnetism, and also in inducing it in substances susceptible of being impregnated. He likewise made numerous experiments with bars of iron and steel placed in the magnetic meridian and exposed to great heats. Dr Hooke took up this subject in 1684. He used rods of iron and steel about seven inches long and one-fifth of an inch in diameter, and he found that they acquired permanent magnetism when strongly heated in the magnetic meridian, and allowed to cool in the same position. The permanency of the effect was greater, and the magnetism stronger, when the rods were suddenly cooled in cold water, so as to give them a very hard temper. He found that the end which was next to the north, or the lower end, of a vertical bar, was invariably a permanent north pole. Even when the upper end alone was quenched, while the rest

of the bar cooled slowly, that end became a sensible south pole. If the same process was adopted when the steel bar lay at right angles to the magnetic meridian, no magnetism was acquired.

The subject of terrestrial magnetism now occupied the attention of our eminent countryman Dr Edmund Halley; and in 1683 he published his *Theory of Magnetism*, which to a certain extent forms the nucleus of more modern hypotheses. He regarded the earth's magnetism as caused by four poles of attraction, two of them near each pole of the earth; and he supposes, "that in those parts of the world which lie nearly adjacent to any one of these magnetic poles, the needle is governed thereby, the nearest pole being always predominant over that more remote." He supposes that the magnetic pole which was, in his time, nearest Britain, was situated near the meridian of the land's end, and not above 7° from the north pole; the other north magnetic pole being in the meridian of California, and about 15° from the north pole of the earth. He placed one of the two south poles about 16° from the south pole of the globe, and 95° west from London; and the other, or the most powerful of the four, about 20° from the south pole, and 120° east of London.

In order to account for the change in the variation, Dr Halley, some years afterwards, added to these reasonable suppositions the very extraordinary one, that our globe was a hollow shell, and that within it a solid globe revolved, in nearly the same time as the outer one, and about the same centre of gravity, and with a fluid medium between them. To this inner globe he assigned two magnetic poles, and to the outer one other two; and he conceived the change in the variation of the needle to be caused by a want of coincidence in the time of rotation of the inner globe and the external shell. "Now, supposing," says he, "such an external sphere having such a motion, we may solve the two great difficulties in every former hypothesis;

for if this exterior shell of earth be a magnet, having its poles at a distance from the poles of diurnal rotation, and if the internal nucleus be likewise a magnet, having its poles in two other places, distant also from its axis, and these latter, by a gradual and slow motion, change their places in respect of the external, we may then give a reasonable account of the four magnetic poles, as also of the changes of the needle's variation." From some reasons which Dr Halley then states, he concludes, "that the two poles of the external globe are fixed in the earth, and that if the needle were wholly governed by them, the variation would be always the same, with some little irregularities; but the internal sphere, having such a gradual translation of its poles, influences the needle, and directs it variously, according to the result of the attractive and directive power of each pole, and consequently there must be a period of revolution of this internal ball, after which the variation will return as before."

This theory excited so much notice, that an application was made to William and Mary for a ship, "in order to seek, by observation, the discovery of the rule for the variation of the compass." The command of a ship of the royal navy was in consequence given to Dr Halley; and, in the accomplishment of the object which he had in view, he performed two voyages, one in 1698, and the other in 1699, in which he traversed various parts of the Pacific and Atlantic Oceans, and obtained such a number of valuable results, that he completed a chart of the variation of the needle, which exhibited to the eye the general law of its phenomena.

The very important discovery of the daily variation of the needle was made in 1722, by Mr Graham, a celebrated mathematical instrument maker in London. While the needle was advancing by an annual motion to the westward, Mr Graham found that its north extremity moved westward during the early part of the day, and returned

again in the evening to the eastward, to the same position which it occupied in the morning, remaining nearly stationary during the night. Mr Graham at first ascribed these changes to defects in the form of his needles; but, by numerous and careful observations, repeated under every variation of the weather, and of the heat and pressure of the atmosphere, he concluded that the daily variation was a regular phenomenon, of which he could not find the cause. It was generally a maximum between ten o'clock A. M. and four o'clock P. M., and a minimum between six and seven o'clock P. M. Between the 6th February and the 12th May, 1722, he made a thousand observations in the same place, from which he found that the greatest westerly variation was 14° 45′, and the least 13° 50′; but in general it varied between 14° 35′ and 14°, giving 35′ for the amount of the daily variation.

The law of the magnetic force, or the rate at which it varies with the distance, had, as we have seen, occupied the attention of Sir Isaac Newton and David Gregory. Numerous experiments were made by various authors for the same purpose, a large collection of which have been published by Scarella, in his treatise *De Magnete*, published at Brescia in 1759. Muschenbroeck made a great number of experiments with the same view; but as the joint action of the four poles was never considered, the precise law of variation remained unknown. Mr Hauksbee and Dr Brooke Taylor employed a much better method, namely, the deviation of a compass-needle from the meridian, produced by the action of a magnet at different distances; but the magnets which they used had improper shapes, and the conclusion which they drew from their experiments was, that the magnetic force decreased much quicker at great distances than at small ones, and that it is different in different loadstones.*

* *Phil. Trans.* No. 368, 396.

Notwithstanding this strange conclusion, the observations to which we have referred were of great value; and Mr Michell * succeeded in deducing from them, in 1750, the true law of magnetic action. "There have been," says Mr Michell, "some who have imagined that the decrease of the magnetic attraction and repulsion is inversely as the cubes of the distances; others, as the squares; and others, that it follows no certain ratio at all, but that it is much quicker at great distances than at small ones, and that it is different in different stones. Among the last is Dr Brooke Taylor and Muschenbroeck, who seem to have been pretty accurate in their experiments. The conclusions of these gentlemen were drawn from their experiments, without their being aware of the third property of magnets just mentioned, which, if they had made proper allowances for, together with the increase and diminution of power in the magnets they tried their experiments with, all the irregularities they complained of (as far as appears from their relations of them) might very well be accounted for, *and the whole of their experiments coincide* with the squares of the distances inversely."

It is to Mr Michell also that we owe the introduction of the torsion balance, for measuring small forces,—an instrument which, as we shall see, was employed with singular success and dexterity by Coulomb in his electrical, magnetical, and hydrodynamical researches: and the science of magnetism is no less indebted to Mr Michell for his invention of the method of double touch, as it is called, by which artificial magnets may be made with greater strength than could have been obtained from the previous method of Duhamel.

The hypothesis of Descartes, who explained the polarity of the needle by means of currents moving rapidly from the equator to the poles, was adopted and defended by

* *A Treatise of Artificial Magnets*, 8vo, Lond. 1750, p. 19.

Euler and Daniel Bernoulli; but we cannot afford any space for such useless speculations. Euler afterwards occupied himself more advantageously for science in attempting to investigate mathematically the direction of the needle on every part of the earth's surface.* Perceiving the intricacy which would arise from the adoption of four poles, as imagined by Halley, he tried the effect of employing two poles not diametrically opposite; and he found, that when a proper position was given them, the variation under the same meridian might be both easterly and westerly, as in Halley's chart. The solution which he has given is founded on the principle, "that the magnetic direction on the earth follows always the small circle which passes through the given place, and the two magnetic poles of the earth;" or that the horizontal needle is a tangent to the circle passing through the place of observation, and through the two points on the earth's surface where the dipping needle becomes vertical, or the horizontal needle loses its directive power. In the application of this principle, Euler makes four different suppositions respecting the magnetic poles: 1. That they are diametrically opposite to each other; 2. That they are in opposite meridians, but not in opposite parallels; 3. That they are on the same meridian; and, 4. That they have every other situation whatever. The first of these suppositions he finds to be quite irreconcileable with the observed phenomena, but in the other three he finds that the variation may be both easterly and westerly in the same meridian. By successive approximations he finds the position of the two magnetic poles in 1757 to be as follows: The north pole in latitude 76° north, and longitude 96° west from Teneriffe; and the south pole in latitude 58° south, and longitude 158° west from Teneriffe. To this dissertation, Euler has

* *Berlin Memoirs*, 1757, 1766.

added a chart of the curves of equal variation, calculated on the preceding principles, and suited to 1757; and their general accordance with observation is very surprising. In a subsequent dissertation, Euler endeavoured to improve his theory, by supposing the two magnetic poles to be at the surface of the earth. The chord joining these poles he calls the magnetic axis, and the middle point of that chord its magnetic centre. Then, if we draw a line from the place of observation to the magnetic centre, and consider this as the base of an isosceles triangle, one of whose sides is the magnetic axis, the other side will be the direction of a freely suspended needle. This hypothesis, though it has various defects, fulfils, as has been well remarked, certain conditions that are essential to a good theory. 1. It gives the needle the approximately accurate positions at the equator, the needle and the axis being then parallel; 2. It fulfils the condition of the needle and axis, forming a continuous line at the poles; 3. It furnishes two points at which the needle would be vertical; and, 4. It gives a series of positions, single for each place, and having a certain, and oftentimes pretty close, approach to the true position.*

The law of magnetic action occupied the particular attention of M. Lambert, the celebrated Prussian philosopher, who has published an account of his labours in the Memoirs of the Academy of Berlin for 1756. Having placed a mariner's compass at various distances from a magnet, and in the direction of its axis, he observed the declination of the needle produced by the magnet, and the obliquity of the magnet to the needle's axis. From several observations at different obliquities, he found that the action of magnetism on a lever was proportional to the sine of the angle of its obliquity to the axis of the

* See an excellent paper on Terrestrial Magnetism, in the *Magazine of Popular Science*, May 1836, No. iv. p. 223, 224.

lever or needle. M. Lambert then proceeded to study the effect of distance, and he discovered that the force of a magnet is proportional to the distance of the nearest pole of the magnet from the centre of the needle, diminished by the square of a constant quantity, nearly equal to two-thirds of the length of the needle. This result he found to be true with magnets ten times larger, and needles twice as short; but as the law led him to a strange result, as if the action on a magnet were exerted from a centre beyond itself, he was therefore obliged to take another method of determining the law of action, namely, by a series of experiments on the directive power of the magnet,* from which he inferred, "that the force of each transverse element of a magnet is as its distance from the centre, and its action as a particle of another magnet inversely as the square of the distance." By means of this law, he calculates the position of a very small needle, and draws three of the curves to which it should be a tangent, and these coincide very accurately with some of those which he had observed.

Our learned countryman Dr Robison had been pursuing similar inquiries before he had seen Lambert's experiments. He got some magnets made, composed of two balls connected by a slender rod; and after magnetizing them strongly, he found that the force of each pole resided nearly in the centre of the ball. In this way the attractive and the directive powers of the magnets were easily computed, and the result was, that the force of each pole was inversely as the square of the distance. In no case did the error of this hypothesis amount to one-fifteenth of the whole, and in the calculation for the phenomena of the directive power the errors were still smaller. When Dr Robison had seen Lambert's second memoir, he repeated all his former experiments in Lambert's manner,

* *Memoirs of the Berlin Academy*, vol. xxii.

taking the precaution of keeping the needle in its natural position, which he had not previously attended to; and the results which he now obtained were still more conformable to his conjecture as to the law of variation. Dr Robison tried another method of ascertaining the law of magnetic action. In 1769 or 1770, he constructed a needle of two balls joined by a slender rod, and having touched it with great care, so as to keep the whole strength of the poles near the centre of the balls, he counted the number of oscillations which it performed horizontally in a given time by the force of the earth's magnetism. "He then placed it on the middle of a very fine and large magnet, placed with its poles in the magnetic meridian, the north pole pointing south. In this situation he counted the vibrations made in a given time. He then raised it up above the centre of a large magnet, till the distance of its poles from those of the great magnet was changed in a certain proportion. In this situation its vibrations were again counted. It was tried in the same way in a third situation, considerably more remote from the great magnet. Then having made the proper reduction of the forces corresponding to the obliquity of their action, the force of the poles of the great magnet was computed from the number of vibrations." The results of these experiments were the most consistent with each other of any that Dr Robison made for determining the law of the magnetic force, and it was chiefly from them that he thought himself authorized to say with some confidence, that it is inversely as the square of the distance. When Dr Robison, however, observed some years afterwards, that Æpinus, in 1777, conceived the force to vary inversely as the simple distance, he repeated the experiments with great care, and added another set made with the same magnet, and the same needle placed at one side of the magnet instead of above it. By this arrangement, which greatly simplified the process, the result of the

whole was still more satisfactory. The inverse law of the square of the distance was therefore well established.

Various speculations respecting the cause of the phenomena of magnetism had been hazarded by different authors; but it was reserved for M. Æpinus to devise a rational hypothesis, which embraced and explained almost all the phenomena which had been observed by previous authors. This hypothesis, which he has explained at great length in his *Tentamen Theoriæ Electricitatis et Magnetismi*, published in 1759, may be stated in the following manner.

1. In all magnetic bodies there exists a substance which may be called the magnetic fluid, whose particles repel each other with a force inversely as the distance.

2. The particles of this fluid attract the particles of iron, and are attracted by them in return with a similar force.

3. The particles of iron repel each other according to the same law.

4. The magnetic fluid moves through the pores of iron and soft steel with very little obstruction; but its motion is more and more obstructed as the steel increases in hardness or temper, and it moves with the greatest difficulty in hard-tempered steel and the ores of iron.

The method of making artificial magnets, which was practised by the philosophers of the seventeenth century, was a very simple but a very inefficacious one. It consisted in merely rubbing the steel bar to be magnetized, upon one of the poles of a natural or artificial magnet, in a direction at right angles to the line joining the poles of the magnet. Towards the middle of the eighteenth century, however, the art of making artificial magnets had excited general attention; and it is to Dr Gowin Knight, an English physician, that we are indebted for the discovery of a method of making powerful magnets. This method he kept secret from the public, but it was afterwards published by Dr Wilson. Duhamel, Canton,

Michell, Antheaume, Savery, Æpinus, Robison, Coulomb, Biot, Scoresby, and others, made various improvements on this art, as will be minutely described when we arrive at that part of our subject.

The science of magnetism owes many obligations to Mr John Canton, one of the most active experimental philosophers who adorned the middle of the eighteenth century. In or previous to the year 1756, he made no fewer than 4000 observations on the diurnal variation of the needle, with the view of determining its amount, and investigating its origin. He found the daily change different in different seasons of the year, as shown in the following table.

January.........	7′	8″	July.........	13′	14″
February.......	8	58	August.....	12	19
March.........	11	17	September.	11	43
April..........	12	26	October....	10	36
May...........	13	0	November...	8	9
June...........	13	21	December...	6	58

He found also that the time of minimum westerly variation at London was between eight and nine o'clock A. M., and the time of maximum between one and two o'clock P. M., the needle returning to its morning position about eight or nine in the evening. A series of similar observations were made with nearly the same results by Mr Van Swinden; but this excellent observer discovered, that some time before the hour in the morning when the westerly minimum took place, and after the same hour in the evening, a motion of the needle both to the eastward and westward took place; that is, the morning westerly variation is sometimes preceded by a small easterly variation, and the principal easterly variation in the evening is followed by a small westerly variation.

Canton explained the westerly variation of the needle, and the subsequent easterly motion, by supposing that

the heat of the sun, acting upon the eastern parts of the earth, weakens their influence, as heat is known to do that of a magnet, and consequently the needle will move to the westward. In the same way as the sun warms the western side of the earth in the afternoon, the needle will then take a contrary direction.

One of the ablest cultivators of the science of magnetism was the celebrated Coulomb, who, by the application of the principle of torsion, first used by Michell, determined the correct law of magnetic attractions and repulsions.* After measuring with great nicety, by the torsion balance, the force requisite to make a magnetic bar suspended horizontally deviate any number of degrees from a given position, he was enabled to verify the discovery of Lambert already mentioned, that the effect of terrestrial magnetism is proportional to the sine of the angle which the magnetic meridian forms with the axis of the magnet upon which it acts. By making the homologous poles of two magnetized wires repel each other, he observed the force of torsion which was necessary to overcome certain quantities of their mutual repulsion, and, at the distances 12°, 17°, and 24°, he found that the repulsive forces were as the numbers 3312, 1692, and 864, deviating little from 3312, 1650, and 828, which they would have been had the repulsive force varied in the inverse ratio of the square of the distance. The excess of 42 and 36 in the experimental numbers was owing to the circumstance that it was not a particle, but a portion, of each wire, from which the repulsive force emanated, so that the force of the other particles, being exerted less obliquely, and therefore being stronger at greater distances, ought to produce an excess such as that actually observed. A similar result was obtained when

* See the article ELECTRICITY in the *Encyclopædia Britannica*, vol. viii. p. 586, where the torsion balance is minutely described.

the contrary poles of the magnetized wires were made to attract each other; so that Coulomb concluded that the attractive and repulsive forces exercised by two magnetic particles are inversely as the square of their distances, a result which he confirmed by several other methods than that which we have noticed.

Provided with such a delicate instrument as the torsion balance, Coulomb was enabled to apply it with singular advantage to almost every branch of the science. His first object was to determine the law according to which magnetism is distributed in a magnetic bar. It was of course well known that the magnetism in the middle of the bar was imperceptible, and that it increased according to a regular law, and with great rapidity, towards each of its poles. By suspending a small proof needle with a silk fibre, and causing it to oscillate horizontally, opposite different points of a magnetic bar placed vertically, Coulomb computed the part of the effect which was due to terrestrial magnetism, and the part which was due to the action of the bar: and in this way he obtained the following results, which show the extreme rapidity with which magnetism is increased towards the poles.

Distances from the North End of the Bar.	Intensity of the Magnetism at these Distances.
0 inches	165
1	90
2	48
3	23
4·5	9
6	6

In examining the distribution of electricity in a circular plane, Coulomb found that the thickness of the electric stratum was almost constant from the centre to within a very small distance of the circumference, when it increased all on a sudden with great rapidity. He conceived that

a similar distribution of magnetism took place in the transverse section of a magnetic bar; and, by a series of nice experiments with the torsion balance, he found this to be the case, and established the important fact, that the magnetic power resides on the surface of iron bodies, and is entirely independent of their mass.

The effect of temperature on magnets was another subject to which Coulomb directed his powerful mind; but he did not live to give an account of his experiments, which were published after his death by his friend M. Biot. Coulomb found that the magnetism of a bar magnetized to saturation diminished greatly by raising its temperature from 12° of Reaumur to 680°; and that when a magnetic bar was tempered at 780°, 860°, and 950°, of Reaumur, the development of its magnetism was gradually increased, being more than double at 900° of what it was at 780°. He found also that the directive force of the bar reached its maximum when it was tempered at a bright cherry-red heat at 900°; and that at higher temperatures the force diminished. It is to Mr. Barlow, however, as we shall presently see, that we are indebted for the complete investigation of the influence of temperature on the development of magnetism.

Coulomb made many valuable experiments on the best methods of making artificial magnets, and he subjected all the various processes that had been previously employed to the test of accurate measurement. His experiments on the best forms of magnetic needles are equally valuable; but the most interesting of his researches, and the last to which he devoted his great talents, were those which relate to the action of magnets upon all natural bodies. Hitherto, iron, steel, nickel, and cobalt, had been regarded as the only magnetic bodies; but, in the year 1802, Coulomb announced to the Institute of France, that all bodies whatever are subject to the magnetic influence, even to such a degree as to be capable of accurate measurement. The

substances employed by Coulomb were in the form of a cylinder or small bar, about one-third of an inch in length and one-thirtieth in thickness, and they were suspended by a single fibre of silk between the opposite poles of two powerful steel magnets, placed in the same straight line, and having their opposite poles at a distance exceeding by a quarter of an inch the length of the cylinders. The cylinders were then made to oscillate between the poles of the magnets, and were protected from all motions of the air by a glass receiver. The result of these experiments was, that whatever was the substance of the cylinders, they always arranged themselves in a line joining the poles of the magnets, and returned to that position whenever they were deflected from it. These experiments were made with cylinders of gold, silver, copper, lead, tin, glass, wood, chalk, bone, and every variety of substance, organic and inorganic. The only explanation which Coulomb could give of these phenomena was, either that all bodies whatever were susceptible of magnetism, or that they contained small portions of iron or other magnetic metals, which communicated to them the property of obeying the magnet. In order to investigate this subject, MM. Sage and Guyton prepared highly purified needles of the different metals, and M. Coulomb found that the momenta of the forces with which they were solicited by the magnets were as follows: —

Lead	0·00674
Tin	0·00591
Silver	0·00520
Gold	0·00406
Copper	0·00406

the momentum of torsion alone, for all the needles, being 0·00136, a little more than a fourth of the action which the magnets exert upon the needles.

In order to determine if these phenomena were owing to particles of iron disseminated through the bodies,

Coulomb fabricated needles out of three different mixtures of white wax and iron filings, and he found that the forces exerted by magnets upon these needles were proportional to the absolute quantities of iron which they contain. Coulomb now tried a needle of silver, purified by cupellation, and another needle of silver alloyed with $\frac{1}{320}$th part of iron, and he found that the action of the magnet upon the former was 415 times less than upon the latter. Hence there will be 415 times less iron in the pure than in the impure silver; and since the latter contains $\frac{1}{320}$th part of its weight of iron, the first will contain $\frac{1}{415}$th of $\frac{1}{320}$th, or $\frac{1}{132800}$th, or it will contain 132799 parts of pure silver and one of iron, a quantity of alloy beyond the reach of chemical detection.

Amongst the scientific travellers who contributed to our knowledge of terrestrial magnetism, Baron Alexander Humboldt was one of the most distinguished. Himself an accurate and scientific observer, and possessed of nice instruments and methods of observation, he made numerous accurate observations on the dip and variation of the needle in various parts of the earth, and particularly near the magnetic equator; and, by means of these valuable data, M. Biot was enabled to throw much light on the subject of terrestrial magnetism. Hitherto the magnetic poles had been considered as either on or very near the surface of the earth; but as it had been found impossible to deduce the phenomena of the variation and dip of the needle, philosophers were led to consider the situation of these poles as indeterminate. M. Biot was the first to adopt this view of the subject; and after numerous comparisons, he came to the conclusion, that the nearer these poles were placed to each other, the greater was the agreement between the computed and observed results; and by considering the two poles as indefinitely near each other in the centre of the earth, the computed and observed measures approximated as closely as could be expected.

Hence it was inferred that the phenomena of terrestrial magnetism were not such as are produced by permanently magnetic bodies, but those rather that arise from simple iron or ferruginous masses, which are only temporarily magnetic. In this manner M. Biot was led to express the law of terrestrial magnetism in a complicated formula, which represented the observations with wonderful accuracy.

In the year 1809, Professor Krafft of St Petersburg undertook the very same inquiry, and after comparing the same observations which were used by Biot, with the respective situations of the places where they were obtained, he arrived at the following simple law: "If we suppose a circle circumscribed about the earth, having the two extremities of the magnetic axis for its poles, and if we consider this circle as a magnetic equator, the tangent of the dip of the needle, in any magnetic latitude, will be equal to double the tangent of this latitude." Upon re-examining his former formula, M. Biot found that it was reducible to the above simple law, a coincidence which may be considered as giving it additional confirmation.

One of the most zealous and successful cultivators of magnetical science is Professor Hansteen of Christiania, who published, in 1817, an able work on the magnetism of the earth.* The Royal Society of Denmark proposed, in 1811, the prize question, "Is the supposition of one magnetical axis sufficient to account for the magnetical phenomena of the earth, or are two necessary?" Professor Hansteen's attention had been previously drawn to this subject by seeing a terrestrial globe, on which was drawn an elliptical line round the south pole, and marked *Regio Polaris magnetica*, one of the foci being called *Regio fortior*, and the other *Regio debilior*. As this figure

* *Untersuchungen über den Magnetismus der Erde*, 4to. Christiania, 1817.

professed to be drawn by Wilcke, from the observations of Cook and Furneaux, Hansteen was led to compare it with the facts; and the result of the comparison being favourable, he was induced to study the theory of Halley, which had previously appeared to him wild and extravagant. The result of his researches, however, was favourable to that part of Halley's theory which assumes the existence of four poles and two magnetic axes. Hansteen's Memoir, which was crowned by the Danish Society, forms the groundwork of the larger volume which he published in 1817. In his fifth chapter, on the Mathematical Theory of the Magnet, he deduces the law of magnetic action from a series of experiments similar to those of Hauksbee and Lambert. Assuming that the attraction or repulsion between any two magnetic particles is directly as the intensity of the force, and inversely as some unknown power t of the mutual distance of these particles, and supposing that the magnetic intensity of any particle is proportional to some power r of its distance a from the centre of the magnet, he finds the following expression for the effect F, which a linear magnet would have upon a magnetic point situated any where upon the axis produced:

$$F = \int \frac{x^r\, dx}{(a-x)^t} - \int \frac{x^r\, dx}{(a+x)^t};$$

x being the length of half the axis of the linear magnet, and F (multiplied by a constant quantity, depending on the degrees of magnetism which the point and line possess) representing the force. In conducting the experiments, Hansteen placed a very sensible compass upon a horizontal table, so that the needle pointed to 0°. From beneath the centre of this needle, and perpendicular to its direction or to the magnetic meridian, he drew a straight line upon the table, and divided it into portions, so that *ten* of them were equal to the half axis a of the artificial magnet. This magnet was then placed on the line at different dis-

tances from the needle, and the deviation of the needle from the magnetic meridian which it produced was accurately observed for each distance. Upon comparing the results, and calculating them by the formula, upon the supposition that t was 1 or 3, the differences were very great; but by making $t = 2$, the calculated and observed results agreed remarkably well, as the following table shows:

Values of a, or Distances in half Axes of the Magnet.	Values of F, or Increase of the Force.			
	Observed Values.	Calculated Values.		
		$t = 2$ $r = 1$	$t = 2$ $r = 2$	$t = 2$ $r = 3$
11	1·000	1·000	1·000	1·000
10	1·306	1·334	1·334	1·325
9	1·834	1·835	1·836	1·836
7	3·947	3·938	3·945	3·949
5	11·015	11·072	11·119	11·154
4	22·441	22·245	22·411	23·530

From this remarkable coincidence between the observed and the computed results, Hansteen concludes, that "*the attractive or repulsive force with which two magnetic particles affect each other, is always directly as their intensities, and inversely as the squares of their mutual distance.*" He shews that the undetermined value of r produces almost no effect at considerable distances; and he is inclined to think that $r = 2$, or that *the absolute intensity of any magnetic particle, situated in the axis, is proportional to the square of its distance from the middle point of that axis.* Mr Hansteen has also demonstrated, that *the distance from the middle of a magnet being the same, the force opposite the poles, or in the direction of the axis, is double of the force in the magnetic equator.* If a globe contains at its centre

an infinitely small magnet, Hansteen shews that, *near the magnetic equator, the dip must increase twice as rapidly as the magnetic latitude, and, near the pole, half as rapidly; and that the increment of the dip must be equal to the alteration of the latitude of that part of the globe where the dip is* 54° 44′. Our author also states, that if the earth had only one magnetic axis, whose centre coincided with that of the earth, the lines of equal dip would coincide with those of equal intensity; but as this is far from being the case, his opinion that there are two magnetic axes becomes more probable.

The most valuable part, however, of Professor Hansteen's work is that which relates to the number, position, and revolution of the magnetic poles. Having collected all the observations of value that had been made on the variation of the needle, he proved that there were *four points* of convergence among the lines of variation, namely, a weaker and a stronger point in the vicinity of each pole of the globe. The strongest poles N, S, lie almost diametrically opposite to each other, and the same is true of the weaker poles *n*, *s*. These four poles he found to have a regular motion obliquely, the two northern ones N, *n*, from west to east, and the two southern ones S, *s*, from east to west. The following he found to be their periods of revolution, and their positions, in 1830: —

	Lat.	Long. from Greenwich.	Time of Revolution round each Pole of the Globe.
Pole N	69° 30′ N.	87° 19′ W.	1740 years.
Pole S	68 44 S.	131 47 E.	4609 do.
Pole *n*	85 6 N.	144 17 E.	860 do.
Pole *s*	78 29 S.	137 45 W.	1304 do.

Since the publication of these results, Professor Hansteen had access to the valuable series of magnetical observations made during the British voyages of discovery to the Arctic Regions; and, after a diligent comparison of

them, he obtained new and more accurate determinations of the positions and periods of revolution of the four magnetic poles, but still differing so little from his previous determinations, as to give a high degree of probability to the correctness of the results. He finds from Captain Parry's observations, that in 1819 the pole N must have been situated in north lat. 71° 27′, and the time of its revolution 1890 (in place of 1740 as formerly calculated.) The period of revolution of S he changed from 4609 to 4605, and that of *s* from 1304 to 1303, that of *n* remaining at 860 as before. Professor Hansteen considers N and S as the terminating points of one magnetic axis, and *n* and *s* those of the other axis; and he remarks that these two axes cross each other without intersection, or without passing through the centre of the earth. In reference to the causes of these singular changes, our author considers it possible that the illumination and heating of the earth, during one revolution about its axis, may produce a magnetic tension, as it produces the electrical phenomena. In support of his hypothesis of four poles, Professor Hansteen has shewn very clearly that the changes in the variation and dip of the needle in both hemispheres may be well explained by their motion; but we cannot here enter into these details.

With the view of discovering the nature of the forces by which the phenomena of terrestrial magnetism are produced, Professor Hansteen resolved to ascertain, at different parts of the earth's surface, the *intensity* of its magnetism, and to determine the form of the lines of equal intensity, or, as he calls them, the *isodynamical magnetic lines.* By means of the same needle intrusted to different philosophers, he had observations on the number of its oscillations in a given time made in every part of Europe; and he afterwards undertook a journey to Siberia, to make the observations himself in that interesting magnetical region. From these observations he

deduced the following law, according to which the magnetic intensity varies with the dip of the needle:

Magnetic Dip.	Magnetic Intensity.
0°	1·0°
24	1·1
45	1·2
64	1·3
73	1·4
76⅔	1·5
81	1·6
86	1·7

Professor Hansteen's journey to Siberia was attended with secondary consequences of great value to science. The attention of the Russian government, and the Academy of Sciences at St Petersburg was thus called to the subject of magnetism; and, on the recommendation of Baron Humboldt, the emperor liberally agreed to erect magnetic observatories in suitable stations, for determining every *ten* years, the exact position of the *two lines of no variation* which pass through his empire.

In determining the intensity of terrestrial magnetism, Professor Hansteen observed that the time of vibration of a horizontal needle varied during the day. Graham had previously suspected a change of this kind, but his methods were not accurate enough to prove it. Hansteen, however, found that the *minimum* intensity took place between 10 and 11 A. M. and the *maximum* between 4 and 5 P. M. He concluded also that there was an annual variation, the intensity being considerably greater in winter near the perihelion, than in summer near the aphelion; that the greatest *monthly* variation was a maximum when the earth is in its perihelion or aphelion, and a minimum near the equinoxes; and that the greatest daily variation is least in winter and greatest in summer. He found also that the aurora borealis weakened the magnetic force, and that the magnetic intensity is always weakest when the

moon crosses the equator. In making experiments in the round tower at Copenhagen, he found that the magnetic intensity increased regularly towards the top, where it was a maximum;* and having extended his observations, he obtained the general result, that at the foot of any vertical object, the needle oscillates *quicker* at the *north* side of it, and *slower* at the *south* side; whereas at the upper end it oscillates *quicker* at the *south* side, and *slower* at the *north* side.

In the aërostatic ascent of MM. Gay-Lussac and Biot, they were unable to detect any change in the intensity of terrestrial magnetism at the height of 4000 metres. Saussure, however, had found that the intensity was considerably less on the Col du Géant than at Chamouni and Geneva, the difference in the levels of these places being in the one case 10,000 and in the other 7800 feet, but his observations contradict his conclusion. M. Kupffer has more recently obtained a similar result by observations on Mount Elbrouz, having found a decrease of intensity in rising 4500 feet above his first station; and he explains the result obtained by MM. Gay-Lussac and Biot by supposing that an increase of intensity was produced by the diminution of temperature. Mr Henwood, on the other hand, has made observations at the surface of Dolcoath mine, at 1320 feet beneath its surface, and on a hill 710 feet above the level of the sea, without being able to detect any difference in the intensity. To the late Captain Foster† we owe many valuable observations on the magnetic intensity, made at Spitzbergen and elsewhere. From these he concluded, that the diurnal change in the horizontal intensity, is principally, if not wholly, owing to a small change in the amount of the dip. The maximum took place at about 3h. 30′ A. M., and the minimum at 2h. 47′ P. M., its greatest change amounting to one eighty-third

* The height of the tower is 126 feet.

† *Phil. Trans.* 1828.

of its mean value. Captain Foster is of opinion that these changes have the sun for their primary agent, and that his action is such as to produce a constant inflexion of the pole towards the sun during the 24 hours, an idea which Mr Christie had previously stated.*

About the year 1818, Professor Barlow of Woolwich turned his attention to the subject of magnetism, with the view principally of calculating the effect of a ship's guns on the compass. In trying the effects of different iron balls, he was led to the curious facts,—that there exists round every globe and mass of iron a great circle inclined to the horizon at an angle equal to the complement of the dip of the needle; that the plane of this circle is a plane of no attraction upon a needle whose centre is in that plane; that if we regard this circle as the magnetic equator, the tangent of the deviation of the needle from its north or south pole will be proportional to the rectangle of the sine of the double latitude, and cosine of the longitude; that when the distance of the needle is variable, the tangent of deviation will be reciprocally proportional to the cube of the distance; and that, all things else being the same, the tangents of deviation will be proportional to the cubes of the diameters of the balls or shells, whatever be their masses, provided their thickness exceed a certain quantity.

These results appeared in the first edition of Mr Barlow's *Essay on Magnetic Attractions;* but in the second edition of that work, he has published some curious experiments respecting the relative magnetic power of different descriptions of iron and steel, and on the effect of temperature on the quality and quantity of the attractive power of iron. The results of the first of these series of experiments were as follow, the numbers expressing the proportional magnetic power of the different descriptions of iron and steel.

* *Phil. Trans.* 1827, pp. 345—349.

Malleable iron.........100	Shear steel, hard......53
Blistered steel, soft... 67	Cast iron..............48
Blistered steel, hard . 53	Cast steel, soft.........74
Shear steel, soft...... 66	Cast steel, hard........49

In his experiments on the effects of temperature, Mr Barlow found that every kind of iron and steel possessed a greater capacity for the development of its magnetism when softened by heat than when cold; from which he concludes that its complete development when cold is prevented only by the hardness or resisting power of the metal. At a *white* heat he found that iron lost entirely its magnetic power, a result apparently inconsistent with the preceding conclusion; but, what was a still more extraordinary circumstance, when the *white* heat, at which there was no magnetism, began to subside into a *bright red*, or *red* heat, an *attractive* power shewed itself, the *reverse* of what it had when cold; and after it had passed through these two shades of colour, it resumed the same attractive power which it had when cold, the passage from the negative attraction of red passing into the positive attraction of the cold metal at the point of a red heat, the maximum, however, taking place at a blood-red heat.

The experimental laws of attraction of an iron shell or sphere, obtained by Mr Barlow, were first examined theoretically by Mr Charles Bonnycastle, who deduced them mathematically from the theory of Æpinus, which supposes the two magnetic fluids to be accumulated in the poles of magnets. This theory, however, led to some improbable consequences, and therefore Mr Barlow was induced to adopt that of Coulomb and Biot, with the modification, *that the magnetic power all resides on the surface of iron bodies, and is independent of the mass*,—a modification which enabled Mr Barlow to obtain a general analytical expression of the disturbing power of an iron ball at its surface, as compared with that of the earth, and from which he deduced theoretically all his experimental laws.

These important discoveries enabled Mr Barlow to invent a most ingenious method of correcting the error of the compass, arising from the attraction of all the iron on board ships. This source of error had been noticed by Mr Wales, Mr Downie in 1794, and by Captain Flinders; but it is to Mr Bain* that we owe the distinct establishment and explanation of this source of error. As a hollow shell of iron about four pounds in weight acts as powerfully at the same distance as a solid iron ball of 200 pounds weight, Mr Barlow happily conceived that a plate of five or six pounds weight might be made to represent and counteract the amount of the attraction of all the iron on board a vessel, and therefore leave the needle as free to obey the action of terrestrial magnetism as if there were no iron in the ship at all. After this ingenious contrivance had been submitted to the Admiralty, it was tried in every part of the world; and even in the regions which surround the magnetic pole, where the compass becomes useless, it never failed to indicate the true magnetic direction when the connecting plate was properly applied. At Port Bowen, where the dip is 88°, and the magnetic intensity which acts upon a horizontal needle extremely weak, the azimuth compass on board Captain Parry's ship gave the very same variation as that observed on shore. "Such an invention as this," says Captain Parry, "so sound in principle, so easy of application, and so universally beneficial in practice, needs no testimony of mine to establish its merits; but when I consider the many anxious days and sleepless nights which the uselessness of the compass in these seas had formerly occasioned me, I really should have esteemed it a kind of personal ingratitude to Mr Barlow, as well as great injustice to so memorable a discovery, not to have stated my opinion of its merits, under circumstances so well calculated to put them to a satisfactory trial." For this beautiful invention, the Board of

* *Treatise on the Variation of the Compass.*

Longitude conferred upon Mr Barlow the highest reward of £500; and the Emperor of Russia, who was never inattentive to the interests of science, sent him a fine gold watch and a rich dress chain, for the same contrivance.

A series of beautiful discoveries was made about this time by M. Arago, Mr Christie, and Mr Barlow, on the influence of rotation on bodies both magnetic and non-magnetic. Mr Barlow, so early as 1818 or 1819, had found, that when a plate of iron was made to turn upon its centre, different parts of its circumference had different degrees of magnetic action on the compass; but here there was no effect discovered as due to rotation. In 1821, Mr Christie, in a series of experiments on iron plates, not only found that different parts in the circumference of the same plate had different attracting powers; but *that the same part had a different influence, according as the same plate was made to revolve to the right or left hand.* Mr Christie therefore discovered that there was a *deviation due to rotation*, and that magnetical effects were produced which were nearly independent of the velocity of rotation, and which continued after the rotation had ceased. When the rotation was very rapid, the forces exerted upon the needle were always in the same direction as the forces derived from the slowest rotation, and which continue to act after the rotation has ceased, the former being to the latter nearly as three to two. From all the observations made by Mr Christie, he considers that the direction of the magnetic polarity acquired by rotation, whether at right angles to the line of the dip or not, has always a reference to the direction of the terrestrial magnetic force; and he infers that this magnetism is communicated to it from the earth. "It does not therefore appear from this," says Mr Christie, "that a body can become polarized by rotation alone, independently of the action of another body; so that, if from these experiments we might be led to attribute the magnetic polarity of the

earth to its rotation, we must at the same time suppose a source from which magnetic influence is derived. Is it not, then, possible that the sun may be the centre of such influence, as well as the source of light and heat, and that, by their rotation, the earth and other planets may receive polarity from it?" When these experiments were repeated at Port Bowen in 1825 by Captain Foster, the phenomena were exhibited on a more striking scale.

In December, 1824, Mr Barlow began a series of experiments, with the view of ascertaining whether magnetism, as produced by various processes with iron, could be excited or disturbed by rapid rotation. They were completed in January, but their publication was delayed till June, that an account of them might appear along with those of Mr Christie above mentioned. Mr Barlow's first experiments were made on a 13-inch shell attached to a lathe turned by a steam-engine, the mean speed of which was about 640 revolutions in a minute. The deviation of a needle exposed to its action increased with the velocity, and remained constant while the velocity continued constant, the needle always returning exactly to its original position the moment the motion of the ball ceased. This, therefore, is a phenomenon different from that observed by Mr Christie,—a temporary effect wholly dependent on the velocity of rotation; whereas that observed by Mr Christie was permanent, and nearly independent of the number of revolutions. In examining the direction of the new force impressed upon the iron shell, he found it to be in every case equivalent to a polarization at right angles to the axis of rotation.

Previous to the publication of these experiments, and without any knowledge of them, M. Arago had made the remarkable discovery, that if plates of copper and other substances are put into rapid rotation beneath a magnetized horizontal needle freely suspended, the rotatory plate will first cause the needle to deviate from its true direction;

and by increasing the velocity, the deviation will increase, till the needle passes the opposite point, when it will continue to revolve, and at last with such velocity that the eye is unable to distinguish it.

M. Arago was led to this beautiful discovery by a previous series of experiments of great interest. He found that a magnetic needle oscillating above or near any body whatever, such as a plate of metal or a surface of water, gradually oscillated in arcs of less and less amplitude, as if it had been placed in a resisting medium; and, what was particularly remarkable, the number of oscillations performed in a given time was not changed. This curious fact was announced to the Academy of Sciences in Paris on the 22d of November 1824; and he was hence conducted to the still more remarkable discovery of the effects of rotation which we have already mentioned.

M. Seebeck of Berlin repeated the experiments of M. Arago on the influence of plates of metal and other substances in diminishing the amplitude of oscillation; but we must reserve our account of them till we come to the chapter on that subject.

The experiments of M. Arago on the rotation of metallic plates were described and repeated by M. Gay-Lussac in London in the month of March or April 1825; and they excited so much attention, from their connection with the effects observed by Mr Barlow, that Mr Babbage and Mr Herschel immediately erected an apparatus for repeating them. In their first trial, the deviation of the needle did not exceed 10° or 11° with a revolving plate of copper. In order to enlarge the visible effect, they reversed the experiment, in order to try whether discs of copper and other non-magnetic substances might not be set in motion if suspended over a revolving magnet. A horse-shoe magnet, capable of lifting twenty pounds, was made to revolve rapidly about its axis of symmetry placed vertically. A circular disk of copper, six inches in diameter

and one twenty-fifth of an inch thick, was suspended centrally over it, by a silk thread just capable of supporting it. A sheet of paper being interposed, and the magnet set in motion, the copper began revolving in the same direction, at first slowly, but with an accelerating velocity. On reversing the motion of the magnet, the velocity of the copper was destroyed gradually. It stopped for an instant, and then immediately began to revolve in the opposite direction. Screens of paper, glass, wood, copper, tin, zinc, lead, bismuth, were interposed betwixt the magnet and the copper, but they exerted no sensible interceptive power. But when tinned iron plate was interposed, the magnetic influence was greatly diminished by one plate, and almost annihilated by two thicknesses of it. A piece of iron connecting the two poles of the revolving magnet produced the same effect. The substances in which signs of magnetism were developed by the revolving magnet, were copper, zinc, silver, tin, lead, antimony, mercury, gold, bismuth, and carbon in the state in which it is precipitated from carburetted hydrogen in gas-works. By getting plates of different metals cast in the same mould, they found that the proportional intensity of magnetic action for each respectively was as follows:

Zinc............1·11	Lead.........0·25
Copper........1·00	Antimony..0·01
Tin.............0·51	Bismuth....inappreciable.

M. Arago had observed the very remarkable fact, that if the disc of copper be cut from the circumference towards the centre, like radii, but without taking away the metal, the action upon the needle is greatly diminished. After verifying this result, Messrs Babbage and Herschel ascertained that re-establishing the metallic contact with other metals, restored, either wholly or very nearly, the original power of the plate, even though the soldering metal had a very feeble magnetic power. The law of the force, with

a decrease of distance, they found to vary between the square and the cube. "The rationale," says Messrs Babbage and Herschel, "of these phenomena, as well as of those observed by Mr Barlow in the rotation of iron, which form only a particular case (though certainly the most prominent of any) of the class in question, seems to depend on a principle which, whether it has or has not been before entertained, or distinctly stated in words, it may be as well, once for all, to assume here, as a *postulatum*, viz. that *in the induction of magnetism, time enters as an essential element, and that no finite degree of magnetic polarity can be communicated to or taken from any body whatever, susceptible of magnetism in an instant.*

The preceding results were verified by Mr Christie, who found, that when a thick plate of copper revolved under a small magnet, the force which deflected the needle varied inversely as the fourth power of the distance; but when the copper discs were small, and the magnets large, the power of the distance was between the square and the cube; when the plates were of different weights, the force was nearly in the ratio of the weights at small distances, but at smaller distances it varied in a higher ratio.

The discovery of two poles of maximum cold on opposite sides of the north pole of the earth, which was announced by Sir David Brewster in 1820, led him and other authors to the opinion that there might be some connection between the magnetic poles and those of maximum cold. "Imperfect," says he, "as the analogy is between the isothermal and magnetic centres, it is yet too important to be passed over without notice. Their local coincidence is sufficiently remarkable, and it would be to overstep the limits of philosophical caution to maintain that they have no other connection but that of accidental locality; and if we had as many measures of the mean temperature as we have of the variation of the

needle, we might determine whether the isothermal poles were fixed or moveable." And he concludes his paper on the mean temperature of the globe with the following paragraph: "Having thus endeavoured to establish a new law of the distribution of heat over the surface of the globe, it might be no uninteresting inquiry to investigate the causes which have modified in so remarkable a manner the influence of the solar rays. The subject, however, is too comprehensive and too hypothetical to be discussed at present. How far the general form and position of the continents and seas of the northern hemisphere may disturb the natural parallelism of the isothermal lines to the equator, — to what extent the current through Behring's Strait, transporting the waters of warmer climates across the polar seas, may produce a warm meridian in the direction of its motion, and throw the coldest parts of the globe to a distance from the pole, — whether or not the magnetic, or galvanic, or chemical poles of the globe (as the important discoveries of Mr Oersted entitle us to call them,) may have their operations accompanied with the production of cold, one of the most ordinary effects of chemical action, — or whether the great metallic mass which crosses the globe, and on which its magnetic phenomena have been supposed to depend, may not occasion a greater radiation of heat in those points where it develops its magnetic influence, — are a few points which we may attempt to discuss when the progress of science has accumulated a greater number of facts, and made us better acquainted with the superficial condition as well as the internal organization of the globe." *

The two poles of maximum cold, which will likely perform an important part in the future history of terrestrial magnetism, are situated, according to Sir David Brewster, as follows, according to the best observations made both near them and at a distance. The American pole is

* *Edinburgh Transactions*, 1820.

situated in latitude 73° north, and longitude 100° west from Greenwich, a little to the east of Cape Walker; and the Asiatic pole in latitude 73° north, and longitude 80° east, between Siberia and Cape Matzol on the Gulf of Oby. Hence the two warm meridians will be in west longitude 10° and east longitude 170°, the latter passing through Lord Mulgrave's range, and the former between St Helena and Ascension Island. The two cold meridians, or those which pass through the poles of maximum cold, will be in west longitude 100° and east longitude 80°, the latter passing near Mexico and through Bathurst Island, and the former through Colombo in Ceylon, Berar in Hindustan, and crossing the Oby a little to the west of Narym in Siberia. The following is the formula which the same author has given for the mean temperature at any point of the globe, T being the mean temperature required, t the maximum equatorial temperature, τ the minimum temperature at each of the cold poles, and δ, δ' the distances of the place from the two cold poles.

$$T = (t - \tau)\ (\sin.^n \delta \,.\, \sin.^n \delta') + \tau.$$

The distances δ, δ' are found from the formulæ.

$$\cos.\ \delta = \frac{\cos.\ L\ (\cos.\ L - \theta)}{\cos.\ \theta} \text{ and}$$

$$\text{tang.}\ \theta = \cos.\ M\ \text{tang.}\ L\,;$$

in which L is the colatitude of the pole of maximum cold, l the colatitude of the place, and M the difference of longitude between the place and the pole of maximum cold. The values of t and τ have been determined with considerable accuracy, t being nearly 82°·8 Fahrenheit, and τ from 0° to $-3\frac{1}{2}$°. The exponent n is nearly $\frac{5}{4}$ths, but future observations may induce us to increase or diminish it.

Now, it is a remarkable circumstance that the same formula, *mutatis mutandis*, expresses the magnetic intensity of magnetism at any point of the earth's surface, the intensity at the two magnetic poles being supposed equal.

If we call S the maximum number of seconds in which any number n of oscillations are performed which takes place at the island of St Thomas on the west coast of Africa, and s the minimum number of seconds in which n oscillations are performed which takes place at the magnetic poles, then the intensity I will be

$$I = (S - s)\ (\sin.^{n} \delta \sin.^{n} \delta') + s,$$

δ and δ' being determined by the formulæ already given, adopting the position of the poles in the preceding page. The values of S and s, according to Captain Sabine and Hansteen, will be about $370''$ and $262\frac{1}{2}''$. This formula will give for the *isodynamical lines*, or those of equal intensity, a series of returning curves of the nature of Lemniscates, almost similar to those drawn by Captain Sabine, and given in a future figure, and exactly like the polar isothermal lines.

The connection thus indicated between the heat and the magnetism of the earth has been studied by succeeding authors, and the general principle has been adopted by many distinguished philosophers. Dr Traill expressed the opinion, "that the disturbance of the equilibrium of the temperature of our planet by the continual action of the sun's rays on its intertropical regions, and by the polar ices, must convert the earth *into a vast thermo-magnetic apparatus*;" and "that the disturbance of the equilibrium of temperature even in stony strata may elicit some degree of magnetism." Mr Christie thinks it "not improbable that difference of temperature may be the primary cause of the polarity of the earth, though its influence may be modified by other circumstances." M. Ampère, who ascribes magnetism to transverse electrical currents, thinks that the strata of our globe may form considerable galvanic arrangements, and that the electric currents may be affected by the rotation of the earth. M. Oersted remarks, in a recent treatise on thermo-electricity, "that the most efficacious excitation of electricity upon the earth appears to

be produced by the sun producing daily evaporation, deoxidation, and heat, all of which excite electrical currents." After stating that the sun daily produces electric currents, and these currents magnetism, he observes, that "thus the earth seems to have a *constant magnetic polarity*, produced in the course of time by the electrical currents which surround it, and a *variable magnetism*, produced immediately by the same current." As the sun produces different effects on water and solid bodies, Oersted supposes that the intensity will vary in the same parallel, and the direction of the needle will be oblique to the equator, in consequence of the lines of equal electro-magnetic intensity being twice bent by the influence of the two great masses of continent. "The yearly and daily change," he observes, "must occasion yearly and daily variations. As to the variations comprehended in greater periods, we might perhaps attribute them to a *motion of the coolest points in such continents*, which, it appears, cannot remain the same for ever, because the currents of warmer air must principally be directed to such points." Analogous views have been recently stated by M. Kupffer, in a memoir read in 1829 to the Russian Academy, in which he adopts explicitly Sir David Brewster's opinions of the existence of two cold poles distant from the pole of revolution. "But this distribution of temperature," says he, "*appears also to have a great influence on the distribution of the intensity of terrestrial magnetism.* This would no doubt be the case if it is true, as I have tried to shew in another memoir, that terrestrial magnetism resides at the surface of the globe. We have here the choice between two hypotheses,—either the earth should be considered as a magnet existing by itself, and then the intensity of its magnetism will be the inverse of its temperature; or it receives its influence from without, and is only like a piece of soft iron, to which the presence of a distant body communicates magnetism, and then the intensity of its magnetism

will increase with its temperature. Though the first of these hypotheses has been hitherto generally adopted, yet the second acquires some probability from the discovery of the magnetic influence of the solar rays, and of the known relation between the diurnal variations of the declination of the needle and the course of the sun." The connection between the poles of maximum cold and those to which the isodynamical magnetic lines are related, is considered by Dr Dalton as a probable supposition. "If the idea," says he, "suggested by Sir David Brewster in the Transactions of the Royal Society of Edinburgh, vol. ix. 1821, be correct (and there seems great reason to believe it to be so,) namely, *that there are two poles of greatest cold in the northern hemisphere*, the above observation will enable us to see the natural cause of this remarkable fact. The lands within the arctic circle, in the absence of the sun, must depend upon the south-west winds from the two great oceans for their winter heat. Those parts of the eastern and western continents which are most remote from the ocean, as measured along the curvilinear tracts of the current of air, must receive that air in great measure deprived both of its vapour and its temperature. Accordingly it is found that the temperature of the north-east parts of such continents exhibits the extreme of cold. Probably a latitude of 75° north, and a longitude of 90° east and 90° west, would be found nearly equally cold, and to exceed any other place on the surface of the globe in this respect; and it would be a curious coincidence if Professor Hansteen's two supposed northern magnetic poles should be found in the same positions as the two poles of extreme cold."*

In a general history of magnetical discoveries, it may be proper to take some notice of the very curious experiments which have been made respecting the influence of the

* *Meteorological Observations and Essays*, second edition, 1834, p. 215.

solar rays in the production of permanent magnetism, although, according to the generally received opinion, the existence of such an influence has not been established; but if the propriety of doing this had been doubtful, the observation just made by M. Kupffer, as connecting this supposed property of violet light with terrestrial magnetism, would have removed the doubt. Dr Morichini, an eminent physician in Rome, was the first who announced it as an experimental fact, that an unmagnetized needle could be rendered magnetic by the action of the violet rays of the sun. His experiments were successfully repeated by Dr Carpi at Rome, and the Marquis Ridolfi at Florence; but M. d'Hombre Firmas at Alais in France, Professor Configliachi of Pavia, and M. Bérard of Montpellier, failed in obtaining decided magnetic effects from the violet rays. In 1814, Dr Morichini exhibited the actual experiment to Sir Humphry Davy, and in 1817 Dr Carpi shewed it to Professor Playfair. A few months after Sir Humphry witnessed the experiment, the writer of this article met him at Geneva, and learned from him the fact, that he had paid the most diligent attention to one of Morichini's experiments, and that he saw, with his own eyes, an unmagnetized needle rendered magnetic by violet light. The following account of the experiment made by Dr Carpi was given to us verbally by Professor Playfair, who approved of the statement of it which we drew up at the time. "The violet light was obtained in the usual manner, by means of a common prism, and was collected into a focus by a lens of a sufficient size. The needle was made of soft wire, and was found upon trial to possess neither polarity nor any power of attracting iron filings. It was fixed horizontally upon a support by means of wax, and in such a direction as to cut the magnetic meridian at right angles. The focus of violet rays was carried slowly along the needle, proceeding from the centre towards one of the extremities, care being taken

never to go back in the same direction, and never to touch the other half of the needle. At the end of half an hour after the needle was exposed to the action of the violet rays, it was carefully examined, and it had acquired neither polarity nor any force of attraction; but after continuing the operation twenty-five minutes longer, when it was taken off and placed on its pivot, it traversed with great alacrity, and settled in the direction of the magnetical meridian, with the end over which the rays had passed turned towards the north. It also attracted and suspended a fringe of iron filings. The extremity of the needle that was exposed to the action of the violet rays repelled the north pole of a compass needle. This effect was so distinctly marked as to leave no doubt in the minds of any who were present, that the needle had received its magnetism from the action of the violet rays." In this state of the subject, Mrs Somerville made some simple and well-conducted experiments, which seemed to set the question at rest, from the distinct and decided character of the results. A sewing needle, an inch long, and devoid of magnetism, had one half of it covered with paper, and the other exposed to the violet rays of the spectrum, five feet distant from the prism. In two hours it acquired magnetism, the exposed end exhibiting north polarity. The *indigo* rays produced an equal effect, and the *blue* and *green* the same in a less degree. The *yellow*, *orange*, and *red* rays had no effect even after three days' exposure to their action. Pieces of blue watch-springs received a higher magnetism. When the sun's light fell upon the exposed end through blue coloured glass, or through *blue* or *green* riband, the same magnetic effects were produced.

The experiments of Mr Christie, an account of which was read to the Royal Society a short time before Mrs Somerville's, confirmed her results to a certain degree, by a different mode of observation. He found that the

compound solar rays possessed magnetic influence, and exhibited it in their effect of diminishing the vibrations of magnetized and unmagnetized steel needles, and also needles of copper or of glass, by making them oscillate in the sun's white ray. Mr Christie, however, has recently remarked, that as his experiments have not succeeded on repetition by Mr Snow Harris, when made in a vacuum, his results must have been owing to currents of air. In justice to Mr Christie, however, we must mention, that Professor Zantedeschi repeated Mr Christie's experiments at Pavia, under an Italian sun, with a needle a Paris foot long, and obtained a striking result. This needle, when drawn from its position of equilibrium through an area of 90°, performed four oscillations in 30″, the last of which had a semi-amplitude of 70°. In the solar rays it performed in 30″ four oscillations, the last of which had only a semi-amplitude of 60°. When he exposed to the sun the north pole, the semi-amplitude of the last oscillation was 6° less than that of the first, while by exposing the south pole this last oscillation became greater than the first. The experiments of Baumgartner and Barlocci tended to confirm these results. The former found that iron wires polished on a part of their length are magnetized by white solar light, exhibiting a north pole on the polished part; and the latter has shewn that an armed natural loadstone, which carried 1½ Roman pound, exhibited, after three hours' exposure to the strong light of the sun, an increase of energy equivalent to 2 ounces, or ⅙th of a pound, while another larger one, which carried 5 pounds 5 ounces, had its strength nearly doubled by two days' exposure. Zantedeschi tried an artificial horse-shoe loadstone, which carried 13½ ounces; after three days' exposure to the sun it carried 3½ ounces more, and by continuing its exposure its power increased to 31 ounces. An oxidated magnet gained most power, and a polished one none. He found also that the north pole of a loadstone exposed to the

sun's rays concentrated by a lens acquires strength, while its south pole, similarly exposed, loses it.

Notwithstanding all these results, the general opinion seems now to be, that light does not exercise any decided effect in producing magnetism. The experiments of MM. P. Ries and Moser were made with needles both polished and oxidated, and also with wires half-polished; and polarized as well as common light was made to fall upon them in a concentrated state, but no decided effect upon their number of oscillations could be observed; and they state that they think themselves justly entitled *to reject totally a discovery which, for seventeen years, has at different times disturbed science.*

In 1827, Mr Snow Harris communicated to the Royal Society of Edinburgh his *Experimental Inquiries concerning the Laws of Magnetic Forces*, made with a beautiful and accurate instrumental apparatus, invented by the author for examining the phenomena of induced magnetism. With this apparatus he found that the magnetic development in masses of iron by induction is, *cæteris paribus, directly proportional to the power of the inductive force, and inversely as the distance;* and that the forces which magnets develop in a mass of iron at a given distance, within certain limits, may be taken as a fair measure of their respective intensities. From another series of experiments he has shewn, that the absolute force of attraction exerted between a magnet and a piece of iron, varies with the power of the magnet, and consequently with the force induced in the iron, *cæteris paribus;* and that when the force induced in the iron is a constant quantity, while its distance from a temporary or permanent magnet is variable, *the absolute force varies with the distance.* This result was not only apparent when the magnetic force was varied by induction, but was also satisfactorily shewn when varied by magnets of which the relative powers of induction were previously ascertained.

Mr Harris made a number of nice experiments on the absolute force of attraction and repulsion between two magnetized bodies, which he found to be in the inverse ratio of the square of the distance. When, in the case of attraction, the magnets, however, were nearly approximated in relation to their respective intensities, the increments in the forces began to decline, and in some instances at near approximations the absolute force was in the simple inverse ratio of the distance. In the experiments with the repelling poles, the deviations from the regular force were still more considerable, and, what is curious in this case, the force became less and less, until the polarity of the weaker magnet appeared to be so counteracted by induction, *that the repulsion was at length superseded by attraction*. Mr Harris next proceeded to determine the law according to which the forces are developed in different points of the longitudinal magnetic axis between the centre and poles of a magnet, and he found that it varied directly as the square of the distance from the magnetic centre,—a law which is uniform in bars of steel regularly hardened and magnetized throughout. This law of distribution is exactly the same as that which has been given by Hansteen.

Mr Harris has also published other two memoirs in the Philosophical Transactions for 1831, the first *On the Influence of Screens in arresting the progress of Magnetic Action*, and the second *On the Power of Masses of Iron to control the Attractive Force of a Magnet*, of both of which some account will be found in a subsequent section. In his latest paper, *On the Investigation of Magnetic Intensity by the Oscillations of the Magnetic Needle*, he exposed an oscillating magnetic bar to a bright sunshine; and though he observed the effect noticed by Mr Christie, which that philosopher ascribed to the influence of the sun's rays, yet he found that they all disappeared when the needle was made to oscillate in an exhausted receiver

M. Haldat of Nancy communicated, in 1830, to the society of that city, the results of some interesting researches on the incoercibility of the magnetic fluid, or its power of exerting its influence through all bodies, even the most dense,—a property which is not possessed by light, heat, or electricity. In this research he adopted various methods of observation, and interposed a great variety of substances; and from the numerous experiments which he made, he has drawn the following conclusions:—1. That the agent or fluid by which the magnetic phenomena are explained is incoercible in the present state of the science; 2. That iron, considered as presenting an exception to this law, coerces the magnetic influences only by acquiring itself the magnetic state; 3. That incandescence does not give to bodies the power of coercing the magnetic influence. In a previous memoir, M. Haldat had obtained some interesting results on the production of magnetism by friction. He found that all hard bodies may, by means of friction, assist in the decomposition of the magnetic fluid, if their action is promoted by the combined action of magnets which, by themselves, are incapable of producing it. If a piece of soft wire, for example, four inches long, and 1-25th of an inch in diameter, is placed horizontally between two bar-magnets, with their opposite poles facing each other, and at such a distance that the wire cannot be magnetized, it will receive distinct magnetism by friction with all hard bodies, such as copper, brass, zinc, glass, hard woods, &c. M. Haldat employed the ingenious process of M. Gay-Lussac, of magnetizing soft iron by torsion, in neutralizing the wires before they were magnetized. If they are twisted after receiving magnetism, they will preserve the magnetism which they had received before torsion; but if, after being twisted, they are twisted in an opposite direction, they will become perfectly neutral.

M. Haldat likewise made some interesting experiments

on the effect of the coercive force in steel on the magnetism produced by rotation, and he found that the force with which a revolving steel disc dragged round a magnetic needle, was in the inverse ratio of the coercive force of the steel. When the discs were not hot, they had the same effect as those at the ordinary temperature. We owe also to M. Haldat an interesting paper on magnetic figures. Figures of any kind, when traced by the pole of a magnet, on a plate of steel, are rendered visible by sifting upon the invisible tracings filings of steel, which arrange themselves in the most beautiful manner along the outlines of the figure which has been traced.

A series of very interesting experiments have been recently published by M. Quetelet of Brussels, *On the successive degrees of Magnetic Force which a Steel Needle receives during the multiple frictions which are employed to magnetize it.* These experiments were made principally before 1830, but they were not given to the public till 1833. The following are the general results which were obtained by the author: —

1. When a needle or bar that had never been magnetized, is magnetized to saturation by the method of separate contact, the magnetic force acquired is a maximum in relation to the forces which can be given to the same needle or bar by the subsequent reversals of its poles.

2. The magnetic force which a needle can acquire becomes weaker in proportion as the reversal of its poles has been multiplied. The series of frictions which tend to bring back the poles to their primitive state are more efficacious than the others.

3. This difference between the forces which the needle acquires after the successive reversal of its poles, goes on continually diminishing, and converges towards a limit It depends in general on the size of the needle in relation to that of the rubbing bars, as well as in its force of coercion.

4. A needle cannot receive all the magnetic force which it can acquire, if the frictions do not take place over all its surface; this becomes particularly sensible in the reversal of the poles.

5. The rubbing bars give (*cœteris paribus*) to bars of the same dimensions as themselves a magnetic force equal to that which they possess, and in bars of different dimensions, the forces acquired are as the cubes of their homologous dimensions. The last part of this proposition was long ago established by Coulomb.

6. When we rub magnetic bars with other bars weaker than themselves, the force of the first diminishes in place of increasing: and it appears that the force becomes that which those latter bars would be capable of giving at the first by directly magnetizing them.

7. The relation which exists between the forces which a needle or a bar receives by successive frictions, and the number of these frictions, may be expressed by an exponential formula of three constants.

One of these constants appears to change its value with the size of the bars which are magnetized, at least while these bars have a magnitude which does not exceed that of the rubbing bars, and while they are of the same quality of steel.

In this way we know beforehand the successive degrees of force which a bar takes at each friction, if we have previously determined the law of these augmentations for the same rubbing bars, and for any other bar which we get to serve as the modulus. If the bar which is rubbed has begun to be magnetized, we must calculate first the number of frictions to which this force corresponds, in order to be able to assign the rank of the subsequent frictions, and the magnitude of the corresponding magnetical forces.

8. When the rubbing bars are greater than the bar to be magnetized, from the first complete friction the force

of magnetism is very nearly one half of the force which the magnetized bar will finally possess.

After the twelfth complete friction, the magnetic force differs little from that which the rubbing bars can communicate.

We owe also to M. Quetelet two interesting memoirs on the magnetic intensity of different places in Switzerland, Italy, Germany, and the Low Countries.

The influence of the aurora borealis on the magnetic needle, which was observed by Hiorter at Upsal in 1741, and by Wargentin in 1750, had long induced philosophers to regard it as a magnetic phenomenon; and this was greatly confirmed by the fact, that the south end of the dipping needle points to that part of the heavens to which the rays of the aurora appear to converge. "The aurora borealis," says Dr Robison, "is observed in Europe to disturb the needle exceedingly, sometimes drawing it several degrees from its position. It is always observed to increase its deviation from the meridian, — that is, an aurora borealis makes the needle point more westerly. This disturbance sometimes amounts to six or seven degrees, and is generally observed to be greatest when the aurora borealis is most remarkable.

"This is a very curious phenomenon, and we have not been able to find any connection between this meteor and the position of a magnetic needle. It is to be observed, that a needle of copper or wood, or any substance besides iron, is not affected. We long thought it an electric phenomenon, and that the needle was affected as any other body balanced in the same manner would be; but a copper needle would then be affected. Indeed, it may still be doubted whether the aurora borealis be an electric phenomenon. They are very frequent and remarkable in Sweden, and yet Bergman says, that he never observed any electric symptoms about them, though in the mean time the magnetic needle was greatly affected.

"We see the needle frequently disturbed, both from its general annual position, and from the change made on it by the diurnal variations. This is probably the effect of auroræ boreales which are invisible, either on account of thick weather or daylight. Van Swinden says he seldom or never failed to observe auroræ boreales immediately after any anomalous motion of the needle; and concluded there had been one at the time, though he could not see it. Since no needle but a magnetic one is affected by the aurora borealis, we may conclude that there is some natural connection between this meteor and magnetism. This should farther incite us to observe the circumstance formerly mentioned, viz. that the south end of the dipping needle points to that part of the heavens where the rays of the aurora appear to converge. We wish that this were diligently observed in places which have very different variations and dips of the mariner's needle."

A valuable series of observations on the influence of the aurora borealis on the magnetic needle was made by Dr Dalton, at Kendal and Keswick, during seven years from May, 1786, to May, 1793, and has been published in his Meteorological Observations and Essays, which appeared in 1793. During these observations he noticed the effect which they produced on the magnetic needle, and he was thus led to study the phenomena of the aurora, and to establish beyond a doubt the relation of all its phenomena to the magnetic poles and equator. His views and speculations on this subject we shall detail at some length in a future part of this treatise; but we shall at present give our readers a specimen of the observations which he made on the magnetic needle during the changes of an aurora.

Feb. 12. The aurora appeared at Kendal after 6h. P. M. flaming over two-thirds of the hemisphere. The beams converged to a point in the magnetic meridian, about 15° or 20° to the south of the zenith. The following were the changes which he observed in the needle and in the aurora:

Time. h.	m.	Variation.		Observations.
5	0 P.M.	25°	5′	west.
6	35	24	49	altitude of the clear space south 35°.
6	42	24	55	altitude of do. 20°, streamers bright, east.
6	50	25	0	streamers bright and active all over the illuminated part.
7	2	25	28	
7	5	25	12	
7	10	24	40	disappeared in the west, active east.
7	20	24	35	active about the zenith, light faint.
7	35	24	45	light faint.
8	0	24	45	strong light northward.
8	10	24	45	a large uniform still light covering half the hemisphere, with flashes now and then.
8	35	24	47	
9	15	24	43	streamers no.-west, bright, east; clouds.
9	20	24	43	the aurora bursting out openly.
9	30	24	50	as fine and large a display of streamers as has appeared this evening.
10	0	24	55	
10	15	24	57	the light growing fainter and fainter.
10	35	24	40	

In these observations, the deviation produced by the aurora was 53′. In some cases during the prevalence of auroras Dr Dalton did not observe any perceptible disturbance of the needle.

Professor Hansteen observes, that large extraordinary movements of the needle, in which it traverses frequently with a shivering motion an arc of several degrees on both

sides of its usual position, are seldom, perhaps never exhibited, unless when the aurora borealis is visible; and that this disturbance of the needle seems to operate at the same time in places the most widely separate. "The extent of such extraordinary movements," he adds, "may, in less than twenty-four hours, amount to 5° or $5\frac{1}{2}$°. In most cases, the disturbance is also communicated to the dipping needle; and so soon as the crown of the aurora quits the usual place (the points where the dipping needle produced would meet the sky,) the instrument moves several degrees forward, and seems to follow it. After such disorders, the mean variation of the needle is wont to change, and not to recover its previous magnitude till after a new and similar disturbance."

From an extensive series of accurate observations made by M. Arago at Paris since 1818, the needle was almost invariably found to be affected by auroræ that were seen in Scotland; and so striking was the connection between the two classes of facts, that the existence of the aurora could be inferred from the derangements of the needle. M. Arago has likewise discovered, that, early in the morning, often ten or twelve hours before the aurora is developed in a very distant place, its appearance is announced by a particular form of the curve which exhibits the diurnal variation of the needle, that is, by the value of the morning and evening maxima of elongation. From a number of corresponding observations on the hourly declination made by M. Arago and M. Kupffer, who established at Kasen, near the eastern limit of Europe, one of Gambey's compasses, similar to that used at Paris, these philosophers were convinced that, notwithstanding a difference of longitude of above 47°, the disturbances produced upon the needle by the aurora took place at the same instant. It is a curious fact, however, and one yet unexplained, that during the frequent occurrence of the aurora at Port Bowen, Captain Foster did not observe any

peculiar changes in the direction of the needle, although from his great proximity to the magnetic pole, the diurnal change sometimes amounted to 4° or 5°; and, under such circumstances, the influence of the aurora ought to have been particularly conspicuous. Mr Christie is of opinion that the direction of the needle may be influenced by the electrical state of the clouds; and he found it be so in a very distinct experiment which he made for the purpose. Captain Sir Everard Home had observed the same effect produced during thunder storms; and, in two instances, he found that a needle came sooner to rest during a thunder storm than it had done either previous or subsequent to it, the number of oscillations having been reduced in one case from 100 to 40, and in another from 200 to 120.

During the late journey of Captain Back to the polar regions in 1833, 1834, and 1835, he found that the needle was generally affected by the aurora; and on one occasion the deviation which it produced was 8°. "For nearly a month, however," (previous to the 7th January, 1834,) he remarks, "the needle had not been perceived to be affected by the aurora, which, it may be proper to observe, was always very faint, apparently high, and generally confined to one point of the heavens.* Captain Back repeatedly observed, that when the aurora was concentrated in individual beams, the needle was powerfully affected; but that it generally returned to its mean position when the aurora became generally diffused. On several occasions the needle was restless, and exhibited the vibrating action produced by the aurora when this motion was not visible; and Captain Back states, that he could not account for this, except by supposing the invisible presence of the aurora in full day.

The only metals which were supposed to have a distinct

* Appendix to Captain Back's *Narrative of the Arctic Land Expedition*, &c. p. 601.

and decided power, and were therefore called magnetic metals, are iron, nickel, and cobalt. Mr David Lyon* has lately endeavoured to shew that these metals resemble one another, not only in their principal qualities, but in the numerical values of their qualities; and he adds, that whilst these three magnetic substances have the values above referred to near each other, there are no other substances in which the same values come very near or fall within those of the three magnetic substances. The values to which Mr Lyon alludes are the following:†

	Specific Gravity.	Atomic Weight.	Atoms contained in a given space.
Nickel	8·27	739·51	1118
Iron	7·21	678·43	1062
Cobalt	7·8	738	1057

The preceding speculation, though ingenious and deserving of attention, has however been overturned by some very recent observations of M. Faraday. "*Cobalt* and *chromium*," says he, "are said to be both magnetic metals. I cannot find that either of them is so, in its pure state, at any temperatures. When the property was present in specimens supposed to be pure, I have traced it to iron or nickel."‡

Mr Faraday has very recently published some interesting observations§ *On the General Magnetic Relations and Characters of the Metals.* He is of opinion that all the metals are magnetic, in the same manner as iron, though not at common temperatures, or under ordinary circumstances. He does not allude to a feeble magnetism, uncertain in its existence and source, but to a distinct

* *London and Edinburgh Phil. Mag.* December, 1834, p. 415.

† M. Pouillet, in his *Elémens de Physique*, tom. iii. p. 89, refers to some remarkable analogies which he has observed between the distance of the atoms of bodies and their magnetic properties.

‡ *London and Edinburgh Phil. Mag.* March, 1836, p. 178.

§ *Ibid.* p. 177.

and decided power, such as that possessed by iron and nickel; and his impression is, that there is a certain temperature for each metal (well known in the case of iron, beneath which it is magnetic, but above which it loses all power,) and that there is some relation between this *point* of temperature and the *intensity* of magnetic force, which the body, when reduced beneath it, can acquire. Iron and nickel would then be no more exceptions from the metals in regard to magnetism, than mercury is in regard to liquefaction.

In order to investigate this point, Mr Faraday subjected various metals in their pure state to a temperature from 60° to 70° below the zero of Fahrenheit, but he could not detect in them the least indication of magnetism. The metals tried were the following:

Arsenic.	Lead.
Antimony.	Mercury.
Bismuth.	Palladium.
Cadmium.	Platinum.
Cobalt.	Silver.
Chromium.	Tin.
Copper.	Zinc.
Gold.	Plumbago.

Mr Faraday next proceeded to compare iron and nickel with respect to the points of temperature at which they ceased to be magnetic. Iron loses all magnetic properties at an orange heat, and is then to a magnet the same as a piece of copper. Mr Faraday found that the point at which nickel lost its magnetic relations was very much lower than with iron, but equally defined and distinct. If heated and then cooled, it remained unmagnetic long after it had fallen below a heat visible in the dark; and almond oil can bear and give that heat which makes nickel indifferent to a magnet, its demagnetizing temperature being about 630° or 640° Fahr. In order to determine what relation the temperature which took from a magnet its

power over soft iron had to that which would take from soft iron or steel its power relative to a magnet, Mr Faraday gradually raised the temperature of a magnet, and found that it lost its polarity rather suddenly when scarcely at the boiling point of almond oil, and then acted with a magnet as cold soft iron. It required to be raised to a full orange heat before it lost its power as soft iron. "Hence he concludes, the force of the steel to *retain* that condition of its particles which renders it a permanent magnet, gives way to heat at a far lower temperature than that which is necessary to prevent its particles assuming the *same state* by the inductive action of a neighbouring magnet. Hence, at one temperature, its particles can of themselves retain a permanent state; whilst, at a higher temperature, that state, though it can be induced from without, will continue only as long as the inductive action lasts, and at a still higher temperature all capability of assuming this condition is lost. The temperature at which polarity was destroyed appeared to vary with the hardness and condition of the steel. Fragments of loadstone of very high power were then experimented with. These preserved their polarity at higher temperatures than the steel magnet; the heat of boiling oil was not sufficient to injure it. Just below visible ignition in the dark they lost their polarity, but from that to a temperature a little higher, being very dull ignition, they acted as soft iron would do, and then suddenly lost that power also. Thus the loadstone retained its polarity longer than the steel magnet, but lost its capability of becoming a magnet by induction much sooner. When magnetic polarity was given to it with a magnet, it retained this power up to the same degree of temperature as that at which it held its first and natural magnetism."

Some of the results observed by M. Pouillet * stand in opposition to some of the preceding statements. M.

* *Elémens de Physique*, 2d edit. tom. iii. p. 89, Paris, 1832.

Pouillet considers it as certain that there are *five* simple magnetic bodies, viz.

Iron,	Chrome, and
Manganese,	Cobalt ;
Nickel,	

and in consequence of having observed some remarkable analogies between the distance of the atoms of bodies and their magnetic properties, he was led to suppose that the magnetic limit of different bodies ought to be found at very different temperatures. "I have, indeed," says he, "demonstrated by experiment,—1. That cobalt never ceases to be magnetic, or rather that its magnetic limit is at a temperature higher than the brightest white heat ; 2. That chrome has its magnetic limit a little below the temperature of dark blood-red heat ; 3. That nickel has its magnetic limit about 350° centigrade nearly at the melting point of zinc ; and, 4. That manganese has its magnetic limit *at the temperature of from* 20° *to* 25° *below zero.* * Experiments," continues he, "on these five magnetic bodies seem to prove, 1*st*, That heat acts upon magnetism only in consequence of the greater or less distance which it occasions between the atoms of bodies ; and, 2*d*, That all bodies would become magnetic if we could by any action whatever make their atoms approach within a suitable distance."

Among the latest researches on magnetism are those of Professor Gauss of Göttingen, who has published an account of them in a treatise entitled *Intensitas vis Magneticæ Terrestris ad absolutum mensuram revocatis.* His object is to impart to magnetical observations the accuracy of astronomical ones. By observing the oscillations of a magnetized bar, he finds the product of the horizontal intensity of the earth's magnetism, and the static momentum

* M. Pouillet remarks elsewhere, that manganese does not become magnetic till it is cooled down to 15° or 20° below zero. (*Elem. de Phys.* iii. p. 18.)

of the free magnetism of the bar; and by eliminating the latter from the two equations, he obtains an absolute measure of the former, independent of the magnetism of the bar. The horizontal intensity thus found is then to be multiplied by the secant of the dip of the needle, in order to give the absolute intensity. In this inquiry Professor Gauss found it necessary to deduce from observation the true law of magnetic action, which, from a number of consistent and carefully made experiments, he found to be in the inverse ratio of the square of the distance. From a series of accurate experiments, Professor Gauss found the horizontal intensity at Göttingen, on the 18th September, 1832, to be 1·7821; and taking the exponent of gravity in moving bodies at the place of observation as the unit of force, and using the Paris line and the Berlin pound, he found the absolute horizontal intensity to be 0·0039131; and as he found the dip at Göttingen on the 23d June, 1832, to be 68° 22′ 52″, the absolute intensity of terrestrial magnetism will be

$$\text{Sec. } 68^\circ\, 22'\, 52'' \times 0{\cdot}0039131.$$

Professor Gauss has proposed, and put in practice, a very accurate method of observing the daily variation of the needle, and of determining the time of vibration of a needle or magnetized bar. He fixes a plane mirror on the end of the bar, and perpendicularly to its axis, and by observing the reflected image of the divisions of a scale, by the aid of a theodolite placed at a distance, he is able to observe and to measure the minutest changes.

The magnetized bar employed by Gauss is of much larger dimensions than the bar of Prony's magnetic telescope; the small ones, which he uses as magnetometers, being four pounds weight, and the large ones twenty-five pounds; two of which, when fastened together, form the *apparatus or multiplier* of induction for rendering sensible and measuring the oscillatory movements predicted by a theory founded on Mr. Faraday's great discovery. By

this valuable invention of Professor Gauss, the observer is not under the necessity of approaching the magnetized bar, so that no disturbance is occasioned by the currents of air produced by the proximity of the observer's body, so that observations may be made in the smallest intervals of time.

With apparatus similar to that of Professor Gauss, simultaneous observations have been made in 1834 and 1836, at intervals of five or ten minutes, at Göttingen, Copenhagen, Altona, Brunswick, Leipsig, Berlin, Milan, and Rome. It appears, from the graphic representation of the results, that the smallest inflexions of the horary curves are parallel, and consequently the disturbing causes which produce them simultaneous at Milan and Copenhagen, two of the places of observation, which have a difference of latitude of 10° 13′.

In giving an account of Professor Hansteen's labours, we have briefly noticed his journey in Siberia, and the erection of magnetic observatories by the Emperor of Russia, on the recommendation of Baron Humboldt; and we have also referred to the early researches of this distinguished philosopher. When travelling in the equinoctial regions of America during the years 1799—1804, Baron Humboldt had devoted much attention to the determination of the intensity of the magnetic forces, and of the dip and variation of the needle. Upon his arrival in Europe, he conceived the design of examining the progress of the horary changes of the variation, and the perturbations to which it is subject, by employing a method which had never been adopted on an extended scale. In a large garden at Berlin, he measured, particularly at the period of the equinoxes in 1806 and 1807, the angular alterations of the magnetic meridian, at intervals of an hour, often of half an hour, without interruption, during four, five, or six days, and as many nights. The instrument employed was Prony's magnetic telescope,

suspended according to the method of Coulomb, and capable of being reversed upon its axis. It was placed in a glass frame, and directed towards a very distant meridian mark, the illuminated divisions of which indicated six or seven seconds of hourly variation. In these researches Baron Humboldt was struck with the frequency of oscillations whose amplitude extended beyond all the divisions of the scale, and which repeatedly took place at the same hours before sunrise. "These vagaries of the needle," says the Baron, "the almost periodical return of which has recently been confirmed by M. Kupffer, in the account of his travels in the Caucasus, appeared to me the effect of a re-action of the interior of the earth towards the surface; I should venture to say, of *magnetic storms*, which indicate a rapid change of tension." With the view of investigating the causes of these disturbances, Baron Humboldt proposed to erect similar apparatus on both sides of the meridian of Berlin; but the political tempest of Germany, and his mission to France by the government, delayed the execution of his plan. M. Arago, however, as we have already seen, began and prosecuted his inquiry with singular success.

When Baron Humboldt again fixed his residence in Germany in 1827, he erected one of Gambey's compasses in a magnetic pavilion, without any iron, in the middle of a garden, and began a series of regular observations in the autumn of 1828. At his request, the Imperial Academy and the curator of the university of Kasan erected magnetic observatories at St Petersburg and Kasan; and the imperial department for mines has established similar stations at Moscow, Barnaoul, and Nertschinsk. The academy, too, has sent Mr George Fuss to Pekin, where he has procured the erection of a magnetic pavilion in the convent garden of the monks of the Greek church. Since Mr G. Fuss's return, M. Kowanko, a young officer of mines, continues the horary observations corresponding

to those made in Germany and Russia. Admiral Greig has established one of Gambey's compasses in the Crimea at Nicolaeff. Baron Humdoldt has procured the establishment of a magnetic apparatus at the depth of thirty-five fathoms, in an adit in the mines of Freiberg in Saxony. Baron Von Wrangel has been provided with one of Gambey's compasses at Sitka, in one of the Russian settlements. M. Arago has caused to be erected, at his own expense, one of Gambey's compasses in the interior of Mexico, where the soil is 6000 feet above the sea. The French minister of marine has established a magnetic station in Iceland, and the necessary instruments were erected this summer (1836) at Reikavig; and Baron Humboldt, at the desire of Admiral de Laborde, has sent instruments to the Havannah in Cuba, to furnish a magnetic observatory under the tropic of Cancer.

Some years ago, the writer of this treatise urged a distinguished and influential member of the British government to establish magnetic observatories in England and the colonies, but no steps were taken in consequence of this application. Baron Humboldt has, however, addressed an interesting letter to his Royal Highness the Duke of Sussex, as President of the Royal Society, soliciting this body to extend, in the colonies of Great Britain, the line of simultaneous observations, and to establish permanent magnetic stations, either in the tropical regions on each side of the magnetic equator, or in the high latitudes of the southern hemisphere, and in Canada. We hope that the Royal Society will use its influence with the British government to have this proposal carried into effect, and that this country shall not be exposed to the humiliation of being indifferent to the progress of those branches of scientific inquiry which its extensive influence in various regions of the globe enables it effectually to advance.

CHAPTER II.

ON THE GENERAL PHENOMENA AND PROPERTIES OF MAGNETIC BODIES.

A BODY is said to be magnetic when it has the power of attracting soft iron, either in the subdivided state of iron filings, or in large portions; or of attracting and repelling other magnetic bodies like itself: of taking a particular position when freely suspended, or moving on a pivot: and of communicating magnetism either temporarily to soft or permanently to hard iron in the form of steel. Hence we may arrange the general properties of magnetic bodies under the following heads:—

1. On the attractive power of magnetic bodies upon soft iron.
2. On the attractive and repulsive power of magnets over each other, or over iron either temporarily or permanently magnetized.
3. On the effect of masses of iron on the attractive force of a magnet.
4. On the polarity of magnetic bodies.
5. On the power of magnets to communicate magnetism to other bodies.
6. On the distribution of magnetism in artificial magnets.
7. On the effect of division and fracture on the distribution of magnetism.
8. On magnetic figures.

SECT. I.—*On the Attractive Power of Magnetic Bodies upon Soft Iron.*

The natural magnet or loadstone was for a long time the only body considered as possessing magnetic properties. It is an ore of iron, of a grey colour, and a dark metallic lustre. Its specific gravity is about four and a half times that of water. It crystallizes in the form of the regular octohedron, and it consists of from 85 to 75 parts of iron, and from 15 to 25 parts of oxygen. It is found in almost every part of the world,* and often forms rocks of considerable magnitude; but different specimens of it possesses very different powers of attraction.

The smallest loadstones generally have a greater attractive power in proportion to their size than larger ones. They have been found of such strength, that though weighing only about twenty-five grains, they could lift a piece of iron about forty-five times heavier than themselves. A small magnet set in a ring, and worn by Sir Isaac Newton, is said to have been capable of lifting 746 grains, or 250 times its own weight; and it is stated by Cavallo, that he has seen a loadstone which weighed only about six and a half grains, which lifted a weight of 300 grains.

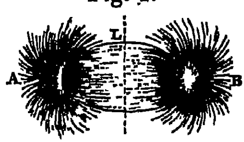
Natural loadstones often possess unequal powers of attraction in different parts of their mass, in consequence of want of homogeneity of structure and composition; and hence a portion has often been cut from a large loadstone which could lift a greater weight of iron than the large one itself, the portion detached having possessed the most suitable structure, and the other part having weakened the action of the powerful part by keeping the body to be lifted at a greater distance from those points

* According to Norman, the best loadstones were those brought from China and Bengal,

where the magnetism was strongest. It is no doubt from a similar cause that small magnets have a greater proportional power than large ones, or that those of two pounds weight have seldom been found capable of lifting more than *ten* times their own weight of iron.

If we now take a natural loadstone L, however shapeless, and, after rolling it in a quantity of iron filings, afterwards withdraw it, we shall find that the filings are accumulated more abundantly in two opposite points A, B, than any other, as shewn in fig. 1. These two points A B are called the poles of the magnet, and are the points of greatest attraction. When either of these poles is held at a distance from the iron filings, the filings will be attracted to it, and will adhere with such force that it is difficult to brush them off.

Fig. 1.



If we suspend a small needle of iron or steel by a fine linen or silken fibre, or balance it on a pivot, and bring the poles of the loadstone L near it, it will be attracted to it in the first case, or will oscillate on its pivot in the second case.

If we make the needle float in water in a glass tumbler, and bring any pole of L on the outside of the tumbler, the needle will be attracted towards the pole, notwithstanding the interposition of the glass; and by using the needle upon a pivot, it will be found that the attractive force of the loadstone is in no respect diminished by the interposition of any substance whatever, except iron, conductors and non-conductors of electricity having no effect whatever in stopping or diminishing the action of the loadstone, unless the interposed body be iron, or contains iron in any of its metallic states.

While the loadstone thus attracts iron, and all bodies containing it in a metallic state, these same bodies exercise a reciprocal attraction upon the loadstone, action and

re-action being equal and opposite. The truth of this may be exhibited by suspending a magnet, and bringing into the vicinity of its poles a piece of soft iron. The magnet will be gradually attracted by the iron, in the same manner as if the iron had been suspended and a pole of the magnet held near it.

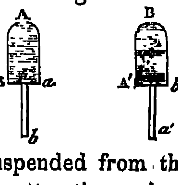
SECT. II.—*On the Attractive and Repulsive Power of Magnets over each other, or over Iron either temporarily or permanently magnetized.*

If we suspend near each other two loadstones, AB, A′B′, like that shown in fig. 1, by two threads T, T, we shall find, by changing the relative position of their poles, A B, A′ B′ that there are certain positions in which these poles attract each other, and others in which they are repelled. By marking the poles which attract each other, such as A, B′, and A′, B, we shall find that the poles which repel each other are A, A′, and B, B′, and that this mutual attraction and repulsion takes place under every change of circumstances.

Fig. 2.

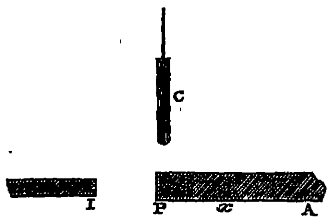
If we suspend a piece of soft iron *a b* from a loadstone AB, we shall find that the end *b* of the iron exercises the same attractive and repulsive power upon the poles A′ B′ (fig. 2.) of a suspended magnet that B did; and in like manner, if the piece of iron *a′b′* is suspended from the pole A′, the end *a′* will exercise the same attraction and repulsion upon the poles of a suspended magnet that A did.

Fig. 3.



SECT. III.—*On the Effect of Masses of Iron on the Attractive Force of a Magnet.*

Fig. 4.



If we suspend a piece of iron C from the arm of a balance, it will be attracted by the pole P of a magnet A, and will descend towards P in virtue of this attraction. If we now place a mass of iron I close to A, the suspended iron C will rise, as if the attractive force of P were diminished. This power of the mass of iron I seems only to extend to a given point within the magnet A, the distance between the magnet and the iron remaining the same; for if the iron C is suspended above a point *x* at some distance from P, the action of I will not be felt at the point *x*, except by diminishing the distance between P and C, or by increasing the neutralizing power of the mass I.

Mr Snow Harris, to whom we owe this experiment, has shewn that a similar effect is produced when the iron I is placed between the magnet PA and the suspended iron C, and also when I is placed below P. In the first of these cases I stops the attraction of P upon C, and acts as a screen.

SECT. IV.—*On the Polarity of Magnetic Bodies.*

If we suspend a loadstone, as in fig. 2, or make it float upon water or mercury, by placing it on a thin plate of cork or wood, it will gradually change its place till it rests in a position where a line joining the poles A, B is nearly

north and south. This is, generally speaking, the case in Europe, the end A, which points northward, deviating in some places from the meridian to the west, in some places to the east; while in other parts of the globe it points exactly to the north. The deviation of the loadstone from the meridian is called its *declination* or *variation*. This property of the magnet is called its *polarity*, or *directive power*; and the pole A, which turns to the north, is called its *north pole*; and the pole B, which turns to the south, its *south pole*. It will now be found that the poles and magnets A, A′, or B, B′, which repel each other, are either both *north* or both *south* poles; and that the north and south poles attract each other. Hence there is in magnetism, as there is in electricity, two opposite powers or principles, namely, the *northern* and the *southern*, or boreal and austral magnetism; and, as in electricity, a *repulsion* takes place between the two powers of the *same* name, and *attraction* between the two powers of an *opposite* name.

The magnetism from which loadstones derive their polarity, or their tendency to direct themselves to particular points of the compass, is obviously derived in some way or other from the earth or its atmosphere; and hence it is called the *Magnetism of the Earth*, or *Terrestrial Magnetism*, which will be treated more fully in a future part of this article.

SECT. V.— *On the Power of Magnets to communicate Magnetism to other Bodies.*

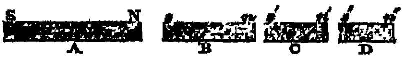
We have already seen, that if a piece of soft iron is suspended to a magnet by the attraction of one of its poles, the iron becomes magnetic, but only during the time that it is in contact with the loadstone. But if we use a piece of hardened iron, or steel, *a b*, and suspend it

as in fig. 3, it will be found to have acquired a permanent magnetism, the strength of which will depend on the power of the natural magnet, A B, and on the time which the steel bar has been suspended. The pole a will be a *north* pole similar to A, and the pole b a *south* pole similar to B; and the little magnet $a\ b$ will possess all the properties of the natural magnet, such as attraction for soft iron, and polarity; and its action upon another little steel magnet $a'\ b'$ made in a similar manner, will be the same as the action of two natural magnets upon each other. A steel magnet thus made is called an *artificial magnet*; and we shall in the sequel consider the magnets of which we speak as steel bars rendered permanently magnetic.

A little magnet $a\ b$ has been made by a very simple process, namely, that of contact with the pole of a natural magnet; but there are more complex and efficacious methods, by which a very high degree of permanent magnetism can be communicated to steel, which will be fully explained in the practical part of this treatise.

In order to communicate magnetism from a natural or artificial magnet to unmagnetized iron or steel, it is not necessary that the two bodies be in contact. The communication is effected as perfectly, though more feebly, when the bodies are separated by space.

Fig. 5.



If the *north* pole N of an artificial steel magnet A is placed near the extremity s of a piece of soft iron B, the end s will instantly acquire the properties of a *south* pole, and the opposite end n those of a *north* pole. The opposite poles would have been produced at n and s if the south pole S of the magnet A had been placed near the iron B.

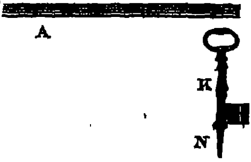
In like manner, the iron B, though only temporarily magnetic, will render another piece of iron C, and this

again another piece D, temporarily magnetic, north and south poles being produced at n', s', and n'' s''.

The magnetism inherent in B, C, and D, is said to be *induced* by the presence of the real magnet A, and the phenomena are exactly analogous to the communication of electricity to unelectrified bodies by induction, the positive state inducing the negative, and the negative the positive, in the parts of a conductor placed in a state of insulation near an electrified body.

In order to shew by simple experiments that soft iron is itself a magnet while placed near a magnet, let A be a magnet and K a key held near its lower edge. A nail N will remain suspended by virtue of its induced magnetism; but if A is withdrawn, or K removed from A, the nail N will instantly fall, the induced magnetism diminishing with the distance.

Fig. 6.



If we hold the key K above a portion of iron filings, they will not be attracted by it; but if we then bring the magnet A near the ring of the key, as in the figure, the iron filings will instantly start up, and be attracted by the key.

We have already noticed, in Sect. 1. that the iron attracted by a magnet re-acts upon the magnet, and attracts it in return. The same is the case with a bar of iron on which magnetism is induced. It re-acts on the magnet which induces its magnetism, and increases its magnetic intensity. Hence we derive a distinct explanation of the remarkable facts, that a magnet has its power increased by having a bar of iron placed in contact with one of its poles, and that we can gradually add more weight to that which is carried by a magnet, provided we make the addition slowly and in small quantities, the

power of the magnet being increased by the re-action of each separate piece of iron that it is made to carry.

If the bar of iron on which magnetism is induced is long, and the strength of the magnet great, a succession of poles is produced along its length, a north pole always following a south pole, and *vice versa.*

These facts enable us to explain the phenomena of magnetic attraction and repulsion, which are necessary consequences of magnetic induction. The magnet attracts a piece of iron by inducing an opposite polarity at the end in contact with it, and the two opposite principles attract each other. In like manner, the north pole of one magnet attracts the south pole of another, and the north and south poles repel each other, in consequence of the attraction and repulsion of the opposite or similar principles. The attraction of iron filings is explained in the same manner. The particle of iron next the magnet has magnetism induced upon it, and it becomes a minute magnet, like B in fig. 5. This particle again makes the next particle a magnet, like C, and so on, the opposite polarities in each particle of the filings attracting one another, as if they were real magnets.

In comparing the amount of the *attractive* force of two *dissimilar* poles of two magnets, with the amount of the *repulsive* force of the two similar poles, it has been found that the former force is considerably greater than the latter. This result is a necessary consequence of the inductive process above described. When the two attracting poles are in contact, each magnet tends to increase the power of the other, by developing the opposite magnetisms in the adjacent halves, and thus increasing their mutual attraction. But when the two repelling poles are brought into contact, the action of each half brought into contact has a tendency to develop in that half a magnetism opposite to that which it really possesses, and thus to

diminish the two similar principles, and weaken their repulsive power. This injurious influence of opposite poles upon the repulsive power of the magnets in action, is finely exhibited when one of the magnets is very powerful, and the other very weak. When the two similar poles are held at a moderate distance, a repulsion is distinctly exhibited; but when they are brought into contact, the stronger *attracts* the weaker magnet, an effect which is produced by its actually destroying the similar weak magnetism in the half next it, and inducing in that half the opposite magnetism, which, of course, occasions attraction.

When the magnet A and the piece of iron B are placed in the same straight line, as in fig. 5, the pole N acts favourably in inducing south polar magnetism at *n*, and north polar at *s*; but it is evident that the remote pole S must tend to weaken the inductive force of N, by inducing, though in a feeble degree, north polar magnetism at *n*, and south polar at *s*. If the soft iron B is placed as in fig. 7, the induced magnetism will be nearly as strong as before, the greater proximity of N tending to produce south polar magnetism in *n*, being compensated by the increased proximity of S tending to produce north polar magnetism in *n*. In the inclined position C the induced magnetism is still stronger, as S acts more powerfully upon *n*; and when the two are parallel, as in fig. 8, the two bars or magnets are in the position most favourable for developing and sustaining the magnetism which they receive or possess.

Fig. 7.

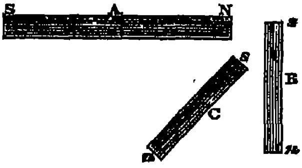
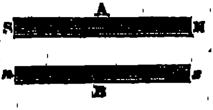


Fig 8.



Hitherto we have considered the natural and artificial magnet as producing magnetism in soft or hard iron, distributed in the same manner as in the inducing magnet; but by the action of one or more magnets, we can distribute the magnetism in various ways, as follows:

In the case of bars, we may have a north pole in the middle of it, and a south pole at each extremity. Thus, in fig. 9, if the magnet NS has its north pole N placed opposite the middle of the soft iron bar *nn*, this bar will have a south pole at *s* and north poles at *n*, *n*. The very same effect will be produced if, as in fig. 10, we place the soft iron bar B between two magnets A, C, whose north poles N, N are nearest the bar. These north poles N, N tend to produce south poles at *s*, *s*, and consequently northern polarity in the middle at *n*. In the preceding case, a south pole may be produced in the middle, and north poles at the ends of the bar, by placing the south poles of the magnets where the north poles are placed.

Fig. 9.

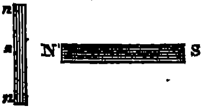
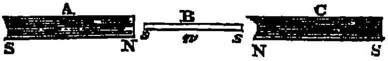
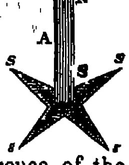


Fig. 10.



In like manner, a piece of soft iron *s s*, *s s*, of the form of a cross, will have south poles at *s*, *s*, *s*, *s*, if the south pole S of a magnet A is placed on or near its centre, as in fig. 11, as it may be conceived to consist of two bars *s s*, *s s*. For the same reason, if a circular plate of soft iron is substituted in place of the cross *ss*, *ss*, and the south pole S of the magnet placed upon or near its centre, that centre will be a north pole, and every point of the circumference of the plate will be a south pole.

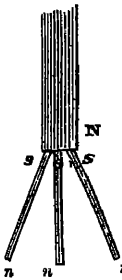
Fig. 11.



A very instructive experiment, founded on magnetic

induction, is exhibited in fig. 12, where several soft iron wires or slender bars *sn*, *sn*, *sn*, are suspended at the north pole N of a magnet N. Each of the ends *s*, *s*, *s*, becomes a south pole by induction from the action of the north, and consequently the lower ends *n*, *n*, *n*, north poles. The south poles *s*, *s*, *s*, have a tendency to repel each other, but are prevented from yielding to their repulsive forces in consequence of their strong adhesion to the north pole N. The north poles *n*, *n*, *n*, however, are free from this restraint, and exhibit their mutual repulsion by their diverging, as shewn in the figure. Hence we see the reason why rows of iron filings adhering to each other, when attracted by a magnet, keep separate from each other by the repulsive forces of the similar poles.

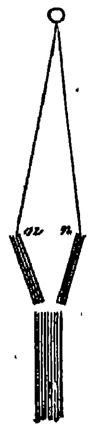
Fig. 12.



In the following form of the experiment, given by Cavallo, the repulsion of both poles is well illustrated. If we suspend two short pieces of soft iron wire *ns*, *ns*, by threads, they will hang in contact in a vertical position. If we now bring the north pole N of a magnet A to a moderate distance from the wires, they will recede from each other, as in fig. 13. The ends *s*, *s*, being made south poles by induction from the north pole N, will repel each other, and so will the north poles *n*, *n*. This separation of the wires will increase as the magnet A approaches nearer them; but there will be a particular dis-

Fig. 13.

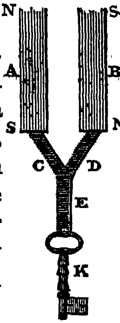
Fig 14.



tance at which the attractive force of N overcomes the repulsive force of the poles *s*, *s*, and causes the wires to converge, as in fig. 14, the north poles *n*, *n*, still exhibiting their mutual repulsion.

The neutralization or destruction of induced magnetism, by two equal and opposite magnetic actions, is shewn in the following experiment, given by Dr Robison. If we take a forked piece of soft iron CDE, and suspend it by the branch D from the north pole of a magnet B, it will be magnetised by induction, and will carry a key at its lower end E, which will be a north pole. If we now apply to the other branch C the south pole S of another and equal magnet A, the key will instantly drop off. This obiously arises from the south pole S inducing a south pole at E, which either destroys or neutralizes the north polar magnetism previously induced by N.

Fig. 10.



Sect. VI.—*On the Distribution of Magnetism in Artificial Magnets.*

It is very obvious, from the preceding experiments, that in regular magnets, with a north pole at one end and a south pole at the other, the two kinds of magnetism, north polar and south polar, are equally and regularly distributed, the one occupying one half of the magnet, and the other the other half. It is obvious also that each kind of magnetism has no intensity at the centre of the magnet, or its middle part, and that it increases, according to some regular law, from that point towards the two poles at the extremities of the magnet.

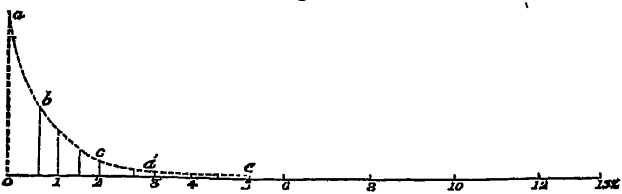
The first person who determined the law of distribution which we have now mentioned was M. Coulomb. The

magnet which he employed for this purpose was a cylinder two lines in diameter, twenty-seven inches long, and its weight 1946 grains; and he ascertained the intensity of magnetism at each point, from its middle to its extremity, by observing the number of oscillations which a small magnetic needle performed in a minute, when it was made to oscillate before different points of the wire. He had previously observed the number of oscillations which the same needle performed out of the sphere of the magnet, and he considered the magnetic intensity as proportional to the difference of the squares of those two numbers of oscillations. The first needle which he employed was three lines in diameter and six lines long, and it was made of such a size, and of such hardness, that its magnetism should not be perceptibly altered by the action of the wire during the experiments; for if any change did take place, the results obtained at different points of the magnet could not be compared. The great length of twenty-seven inches was given to the magnet, in order that its remoter pole might be so distant from the needle that it would be unnecessary to make any allowance for its action upon the oscillations of the needle. In this way Coulomb obtained the following results:—

Distances from the North Pole of the Magnet.	Observed Intensity of the Magnetism at these distances.
0	165
1	90
2	48
3	23
4, 5	9
6	6

The distribution of the magnetism is exhibited in fig. 16 where AN is half of the magnet, and N its north pole; and the ordinates to the curves represent the intensities in the preceding table.

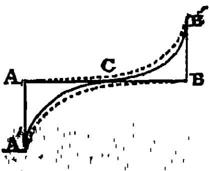
Fig. 16.



These experiments were repeated by Coulomb, with magnets of the same shape and diameter, but of a less length, all other circumstances being unchanged, and he obtained nearly the same results for the three inches of the magnet nearest N; and hence he concluded, that whatever was the length of the magnet, provided it was greater than six or seven inches, the three inches at both its north and south poles gave always the same results as the twenty-seven inch magnet. From this point towards the centre the magnetism became weak and insensible in all of them; and in very long magnets he even found that the ordinates sometimes passed from positive to negative.

M. Biot has remarked that the curve of intensity, as determined by Coulomb, results from the combination of two logarithmic curves ACB′, A′CB, which, setting out from each pole A, B of the magnet AB, would have their ordinates equal and in an opposite direction, as shewn in fig. 17. The intensities calculated upon this supposition agree exactly with the observed results.

Fig. 17.



As Coulomb had examined the distribution of magnetism only in magnets of considerable size, M. Becquerel* was desirous of ascertaining if the law was observed in steel wires of a small diameter, such as $\frac{1}{80}$th of a milli-

* *Ann. de Chimie*, tom. xxii. p. 115; Becquerel, *Traité Expérimentale de l'Electricité et de Magnétisme*, tom. i. p. 365.

metre, or $\frac{1}{2000}$th of an inch. In order to procure such wires, he encased a steel wire one millimetre in diameter in a cylinder of silver, and having drawn out the whole into a wire, the silver was removed by means of boiling mercury. He employed the method used by Coulomb in determining the law of distribution; but, on account of the fineness of the wires, and the weakness of the magnetism which they acquired, he was obliged to make some changes in the method. He obtained, however, the very same results as those given by Coulomb.

A number of interesting experiments on the distribution of magnetism have been made by M. Kupffer of Kasan,* by means of the method of Coulomb. He employed a flat and very narrow needle, twelve millimetres long, and he placed it at a horizontal distance of three decimetres from a cylindrical bar-magnet of cast steel not tempered, 607 millimetres long and 12½ millimetres thick. He began his experiments with magnets that possess a weak degree of magnetism. In magnetizing them, he rubbed the steel bar perpendicularly on the *north* pole of a very strong artificial magnet, and he replaced the bar vertically before the needle, the north pole of the former being uppermost. He found that the south pole was stronger than the north pole, and that the point of indifference, or the neutral point, was nearer the stronger pole than the other. Upon reversing the magnet, the magnetic intensities of its different points increased, and the neutral point approached the middle of the magnet. These changes were produced successively, and the magnet did not attain its final state till it had remained some time in the same position. Kupffer observed, that whenever the magnetic intensities of the bar increased, the neutral point slowly approached the middle point; that this point was always nearer the stronger pole; that a bar magnetized vertically was always more powerful when its north pole

* *Ibid.* tom. xxvi. p. 50.

was downwards; and that a bar magnetized by the method mentioned above was always strongest in the pole immediately produced by that of the magnet.

After detailing his observations with a bar magnetized to saturation, he proceeds to determine the influence exercised by the form of the extremities of the bar on the magnetic intensity, and on the position of the neutral point. A cylindrical bar of steel, cast but not tempered, having been rounded at one of its ends, and magnetized to saturation, was placed fourteen centimetres from a magnetic needle, and in the line of its direction. When its north pole was directed to the south, the force of the rounded north pole was 2·0319, and that of the south pole was 2·1558. In the opposite position of the bar, the magnetic force of the north pole was 2·2198, and that of the south pole 2·3006, the neutral point being in the middle.

The rounded end of the bar was now filed to a point, and made sharper and sharper in every successive experiment, after being each time magnetized to saturation. The force of the sharpened pole diminished with its acuteness. The neutral point receded always from this extremity.

In order to ascertain the distribution of magnetism in the interior of magnets, Coulomb formed sixteen rectangular magnets out of the same piece of steel. Each was six inches long, nine and a half lines wide, and 382 grains in weight. They were annealed at a white heat, without being tempered, in order that he might be certain of having them always in the same state. He magnetized them all to saturation, and formed bundles with a certain number of them, similar poles being placed together. The magnets in each bundle were bound tightly together with a strong silk thread. Each bundle was then placed in a torsion balance, and placed 30° out of the magnetic meridian. The force of torsion necessary to retain it in

this position was a measure of its magnetic intensity. The following were the forces or degrees of torsion necessary to keep the different bundles at rest.

	Degrees of Torsion.
1 magnet	82°
2 magnets united	125
4 magnets united	150
6 magnets united	172
8 magnets united	182
12 magnets united	205
16 magnets united	229

Hence it follows, that the magnetic force of each bundle increases in a ratio much less than that of the number of plates.

Coulomb next determined the magnetic state of each of the magnets composing the bundles of eight and sixteen magnets; and he found that the two outermost magnets, those which formed the surface of the bundles, had a much greater force than the rest.

The first had a force which measured	46
The second	48
And the mean force of all the rest was	30

A single magnet had its directing force 82°, while for sixteen of them united the mean directing force of each was only 14°·3, that is, about the sixth part of the other.

In examining the bundle of eight magnets by the method of oscillation, he found that the two outermost performed twenty oscillations in 90½ minutes, while all the rest performed the same number in from 211 to 278 nearly, shewing the weakness of their magnetism. It is curious that the outermost but one had its poles reversed.

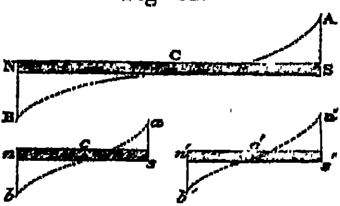
Coulomb also found that a bundle of magnets will take nearly the same degree of magnetism as a single magnet of the same shape and weight; which leads us to believe

that, in magnets of one piece, the magnetism diminishes from the surface to the centre, as in the preceding bundles of magnets.

Sect. VII.—*On the Effect of Division and Fracture in the Distribution of Magnetism.*

As no natural or artificial magnet has ever been seen with only one pole, or one kind of magnetism, it became interesting to determine experimentally the distribution of magnetism in a part of a magnet cut from its north or south extremity. This experiment has been often made, both by cutting it through at the middle or neutral point, or by cutting or breaking off a portion from the end of it. If NS, for example, is a magnet, N its north and S its south pole, and ACB the curve representing the intensity of its magnetism; then, if we cut it through the middle C, each half *ns*, *n's'* will be a complete magnet, with a north pole at *n*, and a south one at *s*, and their neutral points at *c*, *c'*; the curves at *acb*, *a'c'b'*, representing the distribution of their north and south polar magnetism, being similar to the curve ACB of the large magnet of which they are the halves.

Fig. 18.



When Æpinus made this curious experiment, he did not divide the magnet in two, but he set two steel bars end to end, and magnetized them as one magnet, so that this compound magnet had its magnetism distributed as in a single bar, like NS, fig. 18. He then separated them, and found that each bar was a perfect magnet, with two poles. Dr Robison repeated this experiment successfully on some occasions; but he sometimes found indica-

tions of the compound magnet acting as two magnets. We are persuaded that this arose from an imperfect union of the two bars, and not from any defect in Æpinus's experiment. The united ends of the bars should be ground together, so as to be kept in perfect contact, and preserved in this state by a powerful pressure during the time that they are magnetized. If this be done, we have no doubt that they will act on iron filings, and throw them into curves as if they were a single bar, and will, by examination with a fine needle, exhibit the same regular distribution of magnetism which takes place in the most perfect magnet.

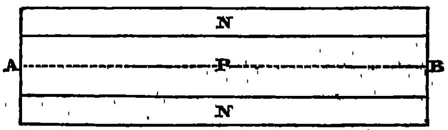
Upon the separation of the magnets thus united, Æpinus found that two poles were instantly developed in each half, but that the neutral points *c*, *c'*, fig. 18, were nearer the interior poles *s*, *n'*, or, what is the same thing, nearer the original neutral point C, than to *n* and *s'*. In the space of about a quarter of an hour it had, however, advanced nearer to the middle points *c*, *c'*, and continued for some hours, and sometimes for days, to advance to these points, which it finally reached, thus completing the regular distribution of the two opposite magnetisms.

Some observations, but not very accurate ones, have been made on the division of magnets in the direction of their lengths. According to Dr Derham, the two portions sometimes have contrary, and sometimes the same poles, as when they were united. When one portion was much thinner than the other, the thinner portion had generally its poles reversed. This experiment does not possess much interest; for it can scarcely be doubted that, if we could divide a magnet in the direction of its length without any violence or concussion, each portion, whether thinner or thicker, would have, when separate, the same polarities as when combined. The experiment would be easily made by pressing two equal steel bars into close

contact, magnetizing them in this state, and then separating them.

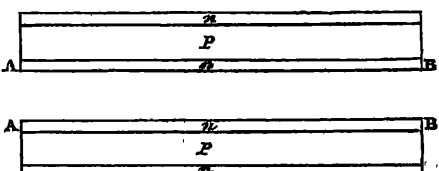
A very remarkable analogy has been pointed out by Sir David Brewster, between the preceding results and those which he has obtained with parallelopipeds of glass which received the doubly refracting structure by being quickly cooled on all their surfaces from a state of red heat. This change is analogous to that of temper in a magnet; and the effect of it is to produce a certain developement of positive and negative double refraction throughout the whole of the parallelopiped of glass. These phenomena will be minutely explained in our article on OPTICS; but we may state at present, that the structure of the glass modifies the action of the ether which it contains, just as the structure of the tempered steel keeps the two magnetisms in an uncombined state.

Fig. 19.



This is shewn in fig. 19, where AB is a thick plate of glass quickly cooled. The middle portion of it P has positive, and the external portions N, N, negative double refraction. The density of the ether in each of these portions varies according to a regular law; and the intensity of the doubly refracting force, at different points both of the positive and negative structures, is represented

Fig. 20.



by a curve formed by the superposition of a straight line and a parabola. If we now cut the parallelopiped of glass into two halves, through the dotted line AB, fig. 19, each half will have the same structure as the whole, as shewn in fig. 20; the parts that were formerly *positive* being now *negative*, and *vice versa*; and the intensity of the doubly refracting force in each half will be represented by the ordinates of a curve formed by the superposition of a straight line and a parabola. This fact is in perfect analogy with the magnetic one, and there are many other remarkable points of resemblance, which we have not space to describe at present.

SECT. VIII.—*On Magnetic Figures.*

In our article on ELECTRICITY we have given an account of the beautiful electrical figures discovered by M. Lichtenberg, and which form one of the most interesting popular experiments in that science. We are indebted to M. Haldat of Nancy for the analogous discovery of magnetic figures, which may be easily produced. For this purpose he employs plates of steel from eight to twelve inches square, and from one-twentieth to one-eighth of an inch thick. The plates which he used were of that kind of steel which is used for the manufacture of cuirasses, so that it did not require to be tempered, being sufficiently hard to preserve the magnetism communicated to it. Figures of any kind may be traced on the surface of the steel plate, either by one magnet or by several combined; and the best form for this purpose is that in which the poles are rounded. In this way we may write upon a steel plate the name of a friend, or sketch a flower or a figure, with the extremity of a magnet. If it is a south pole that we use, all the traces which it makes will have north polar magnetism; and if we

shake steel filings upon the plate out of a gauze bag, the filings will arrange themselves in the empty spaces between the lines traced by the pole of the magnet, and thus represent in vacant steel the name which has been written, or the flower or figure which has been sketched. "These figures," says M. Haldat, "have a perfect resemblance to those which are formed on the surface of non-magnetic plates, namely, wood, card, glass, or paper, under which a magnet is placed. The resemblance between the two sorts of figures, when the magnets and the parts magnetized have the same form, is not only exact in the whole figure, but even in the smallest details. The filings collect at the parts where the magnetism is most intense, they arrange themselves in pencils and radii, and form the same curves which we have represented in fig. 1, page 70. These curves, and pencils, and rays, so similar at the two poles of the same magnet, have such a resemblance that they do not allow us to distinguish the two parts from one another."

M. Haldat has likewise produced these curves by interposing between the tracing magnets and the steel plates solid non-magnetic bodies, such as cards, glass, and even metallic plates that are not ferruginous. This method of producing magnetism in the steel plate by induction gives the same figures; but, in order to be efficacious, the magnet must have its pole carried parallel to and at a small distance from the plate of steel, and must repeat its traces, in order that the magnetism may be sufficiently developed. For rectilineal figures, M. Haldat employs rules with grooves, which keep the motion and distance of the bar invariable; for curvilineal figures he interposes some thin and uniform plate, and he can vary the distinctness of the figures by varying the distance of the tracing pole of the magnet.

In sifting the iron filings upon the steel plate, a gentle vibration of the plate, by tapping its edge with the ring

of a small key, will assist the filings in taking their proper places; but we must avoid such vibrations as will produce regular acoustic figures, unless we wish, as M. Haldat has found to be practicable, to unite the magnetic with the acoustic figures, which produces very interesting and varied forms.

M. Haldat has found that the magnetic figures will continue for six months. In order to remove the magnetism which produces them, he recommends the heating of the plate upon red-hot charcoal, till it is brought to the straw-yellow temperature. In order to render the repolishing of the plate unnecessary, M. Haldat tins it, and the temperature at which the tin melts, when it is required to efface the magnetism, indicates the necessary heat. M. Haldat employs also another method, which is perhaps the best. He places the steel plate upon a block of wood, and by repeated and violent blows of a wooden hammer, he removes the magnetism of the plate, the figures gradually becoming weaker and weaker when the experiment is tried with it in different stages. The effect is often produced in three or four minutes.

As the figures traced on the steel are nothing more than magnets of different forms, and are surrounded on all sides with a substance capable of acquiring the magnetism which may be developed by communication, we might expect, as M. Haldat remarks, that this means of communication between the opposite poles of the magnets would bring them into a neutral state. This, however, is not the case, and the portion of the metal which surrounds the magnetic figure performs the part of the *armature* of a loadstone, and the magnetism is thus kept up. If the figure be a simple rectangle, like that of a bar-magnet, the state of the plate, examined with a small needle, is exactly the same as a bar-magnet, and the parts which surround this magnetic portion, are in a neutral state, as if unconnected with the rectangular space; from which

it follows that the magnetic virtue, which communicates itself so easily by influence, ceases to communicate itself between the continuous parts of a magnetizable body, of which one portion is magnetic, and the rest in a neutral state.

In carrying into effect the preceding method of making magnetic figures, a very great difficulty must be experienced in recollecting the invisible traces made by the pole of the magnet, so as to complete a regular figure or drawing. When the figures are made *immediately*, as M. Haldat expresses it, that is, by the actual contact of the pole of the magnet, without any intermediate body, the best method would be to cover the plate of steel with the slightest coating of grease, and sift upon the surface, through a linen bag, some of the finest flour. The pole of the magnet, while tracing the figures on the steel, will remove the flour, and thus exhibit to the eye an accurate picture of what it has traced; and it will thus be easy to make the magnetic figures more distinct by repeating the traces with the magnet. The same thing may be done by putting an etching ground upon the steel plate, and tracing the figure as before. When the figure is completed, the coating of grease and flour, or the etching ground, must be removed previous to the application of the iron filings.

When the figures are to be produced *mediately*, or by the intervention of a non-magnetic substance, such as paper, card, wood, or glass, a fine dust may in like manner be laid upon the surface; but when the interposed substance will receive the mark of a pencil or sharp point, it would be preferable to attach to the cylindrical pole of the tracing magnet a very short point of a non-magnetic substance, which would make a visible mark on the paper, card, or wood, without strewing any fine dust on their surfaces. By the use of such a point, indeed, we may dispense altogether with the interposed substance,

and communicate the magnetism by induction to the steel plate, in the very same way as if it had been done by the intervention of a non-magnetic plate whose thickness is equal to the length of the short point or tracer affixed to the pole of the magnet.

The magnetic figures might be rendered permanent by covering the steel plate either with a gummy or balsamic solution, which will indurate by exposure to the air; or with a coating of some easily melted substance, which becomes fixed at ordinary temperatures. If we sift the iron filings on the steel plate when covered with such a fluid, the filings will take their magnetic position round the traced lines, and will become fixed by the induration or solidification of the fluid coating.

CHAPTER III.

ON THE MAGNETISM OF BODIES NOT FERRUGINOUS.

SECT. I.—*On the Magnetism of Metals, Minerals, and other Bodies.*

IRON was long regarded as the only body endowed with the property of acting and of being acted upon as a magnet; and though other metals and substances have been recently found to possess the same property, and though all substances whatever have been found by Coulomb to obey the power of a strong magnet, yet it is still a matter of doubt whether the magnetic effects thus produced are owing to a magnetism residing in the proper substance of the body, or are owing to a minute quantity of iron which enters into their composition.

The most magnetic metal next to iron is *nickel*. It receives and retains communicated magnetism longer than any other metal, and needles of nickel have a distinct polarity. These properties have been found in nickel after it has been repeatedly purified, though some authors have stated that they could not detect this property in certain specimens. A very decisive and instructive experiment on the magnetic qualities of nickel was made by M. Biot.* He possessed a needle of nickel which had been purified by M. Thénard. It was 212 millimetres long, six broad, and 5·178 grains in weight. Having made a needle of steel of exactly the same dimensions, and which weighed 4.586 grains, he magnetized them both to saturation, and caused them to oscillate in the magnetic meridian. The nickel needle performed ten

* *Traité de Physique*, tom. iii. p. 126.

oscillations in eighty-seven seconds, and the steel one the same number in forty-five and a half seconds. As the shape of the needles was the same, the momenta of their directive forces were directly as their weights, and inversely as the squares of eighty-seven seconds and forty-five and a half seconds, that is, as 0·3088 to 1, that is, the directive force of the needle of nickel was *nearly one-third* of that of the steel needle. Now, it is impossible to suppose that purified nickel could contain such a large proportion of iron as is necessary to produce such a degree of magnetic polarity, without its being easily recognized by the chemist; and M. Biot supposes that the magnetic power of the nickel might have been still farther increased by the means which are used to modify the coercive power of steel and iron.

A series of careful experiments were made by M. Cavallo, on the magnetism of *brass* when hammered. He found that brass, whether old or new, British or foreign, was made magnetic when placed between two pieces of card, and hammered on an anvil with a common hammer; and that the magnetism thus imparted was always removed by making the brass red hot, and could be again communicated to it. Lest it might be supposed that ferruginous matter might pass to the brass through rents or openings in the card, he hardened a piece of brass by beating it between two large flints, using one piece as a hammer, and the other as an anvil. The hammered brass became magnetic, but not so strongly as before; which arose probably from the rough and irregular surfaces of the flints, which prevented the brass from being hardened as uniformly as it was with the steel hammer. The flints, before and after the experiment, did not possess the slightest magnetism.

The degree of magnetism communicated to brass by hammering is vaguely stated by Cavallo to have been such "as to attract either pole of the needle from about

a quarter of an inch distance." The following are the conclusions which M. Cavallo has drawn from these and other experiments :—

"*1st*, That most brass becomes magnetic by hammering, and loses its magnetism by annealing or softening in the fire, or at least its magnetism is so far weakened by it, as afterwards to be only discoverable when set to float on quicksilver.

"*2d*, The acquired magnetism is not owing to particles of iron or steel imparted to the brass by the tools employed, or naturally mixed with the brass.

"*3d*, Those pieces of brass which have that property, retain it without any diminution after a great number of repeated trials, viz. after having been repeatedly hardened and softened.

"*4th*, A large piece of brass has generally a magnetic power somewhat stronger than a smaller piece, and the flat surface of the piece draws the needle more forcibly than the edge or corner of it.

"*5th*, If only one end of a large piece of brass be hammered, then that end alone will disturb the magnetic needle, and not the rest.

"*6th*, The magnetic power which brass acquires by hammering has a certain limit, beyond which it cannot be increased by farther hammering. This limit is various in pieces of brass of different thicknesses, and likewise of different qualities.

"*7th*, Though there are some pieces of brass which have not the power of being rendered magnetic by hammering, yet all the pieces of magnetic brass that I have tried lose their magnetism, so as no longer to affect the needle, by being made red hot, excepting, indeed, when some pieces of iron are concealed in them, which sometimes occurs; but in this case the piece of brass, after having been made red hot and cooled, will attract the needle more forcibly with one part of its surface than

with the rest of it; and hence, by turning the piece of brass about, and presenting every part of it successively to the suspended magnetic needle, one may easily discover in what part of it the iron is lodged.

"8*th*, In the course of my experiments on the magnetism of brass, I have twice observed the following remarkable circumstance: A piece of brass which had the property of becoming magnetic by hammering, and of losing the magnetism by softening, having been left in the fire till it was partially melted, I found upon trial that it had lost the property of becoming magnetic by hammering; but having been afterwards fairly fused in a crucible, it thereby acquired the property it had originally, viz. that of becoming magnetic by hammering.

"9*th*, I have likewise often observed, that a long continuance of a fire so strong as to be little short of melting hot, generally diminishes, and sometimes quite destroys, the property of becoming magnetic in brass. At the same time, the texture of the metal is considerably altered, becoming what some workmen call *rotten*. From this it appears, that the property of becoming magnetic in brass by hammering, is rather owing to some particular configuration of its parts, than to the admixture of any iron; which is confirmed still farther by observing that Dutch plate brass (which is made, not by melting the copper, but by keeping it in a strong degree of heat whilst surrounded by *lapis calaminaris*) also possesses that property, at least all the pieces of it which I have tried have that property. From these observations it follows, that when brass is to be used for the construction of instruments wherein a magnetic needle is concerned, as dipping needles, variation compasses, &c. &c. the brass should be either left quite soft, or it should be chosen of such a sort as will not be made magnetic by hammering, which sort, however, does not occur very frequently."

These judicious suggestions of M. Cavallo, respecting

the condition of the brass parts of azimuth compasses, were not attended to as they ought, and we have no doubt that various grave errors have arisen from their neglect. Many examples have recently occurred, in which the errors were detected; and it is now the invariable practice of well-informed instrument-makers to reject hammered brass bowls for compasses, and to use those which are cast and turned for the purpose.

M. Cavallo and others have observed, that cobalt, zinc, copper, and bismuth, as well as their ores, are attracted by the magnet and antimony when gently heated. Minerals, which are not metallic, are almost all acted upon by the magnet, particularly where they have experienced the action of fire. The pure earths, and particularly silex, are found to have the same property. Among minerals, the following table shews those which are attracted and those which are not attracted by the magnet; but we place little faith in their accuracy.

Minerals not attracted.	Minerals attracted.
Diamond.	Oriental ruby.
Pellucid crystals.	Chrysolite.
Amethyst.	Tourmaline.
Topaz.	Emerald.
Calcedony, and other crystals whose colouring matter is expelled by heat.	Garnet.
	Several micas containing iron.

Some accurate experiments have been made on mica by M. Biot. The chemical composition and optical structure of different varieties of this mineral vary greatly. M. Biot examined particularly mica from Siberia and mica from Zinwald in Bohemia. Though both were highly pellucid, yet chemical re-agents indicated in each the existence of oxide of iron. In the Bohemian mica it was greatest, and, according to an accurate analysis by

Vauquelin, amounted to 20 per cent. Before the Siberian mica was analyzed, M. Biot tried their magnetic properties. He cut out of each, thin rectangular plates of the same form, which he subdivided into smaller similar pieces, and having united them in a bundle, he suspended each bundle by a silk fibre, and caused each bundle to oscillate in succession between the poles of two strong magnets. The bundle of Zinwald mica performed twelve oscillations in fifty-five seconds, and that of the Siberian mica only seven in the same time. Hence the magnetic powers of the two micas were as 6·8 to 20, the ratio of 49 and 14 to the squares of the number of oscillations. If the oxide of iron, then, be the cause of their magnetic virtue, it should exist in the above proportions of 6·8 to 20; and as it was found to be 20 per cent in the Zinwald mica, it ought to be 6·8 in the Siberian. It is very remarkable that the result of Vauquelin's analysis gave exactly this per centage of the oxide of iron, though it was not known to M. Biot till his experiment had been made.

The existence of magnetism in brass, while there was not the least trace of it either in the copper or zinc of which it is composed, led philosophers to investigate the effects produced by the union of different metals, or by their combination with other substances. *Iron* itself is a simple chemical body. *Steel* is a combination of iron and carbon. The *loadstone* is a combination of iron and oxygen; and as no magnetism is found either in carbon or oxygen, we are naturally led to believe, as M. Pouillet has remarked, that the magnetic fluid resides in the substance of the iron, and that it is carried with the atoms of that metal into all the chemical combinations which they form. We may therefore expect to find magnetic properties more or less developed in all ferruginous bodies, whether the iron be an accidental or an essential ingredient; and indeed cast iron, plumbago, and the oxides

and sulphurets of iron, exert a sensible action on the magnetic needle.

These views, however, are not in unison with facts which seem to have been well ascertained. Dr Matthew Young found, that the smallest admixture of antimony was capable of destroying the polarity of iron; and M. Seebeck states, that an alloy of one part of iron and four parts of antimony was so completely destitute of magnetic action, that, even when it was put into rotation, it exerted no power over the magnetic needle. The magnetic qualities of nickel also are destroyed by a mixture with it of other metals. Chenevix found that a very small proportion of arsenic deprived a mass of nickel, which had previously exhibited a strong magnetic power, of the whole of its magnetism; and Dr Seebeck found that an alloy of two parts of copper with one of nickel, was entirely devoid of magnetism, and on this account he recommends it as well suited for the manufacture of compass-boxes. On the other hand, Mr Hatchet ascertained, that when a large proportion of *carbon* or *sulphur* or *phosphorus*, was combined with iron, the iron was enabled fully to receive and retain its magnetic properties; but he at the same time found that there was a limit beyond which an excess of any of these three substances rendered the compound wholly incapable of receiving magnetism.

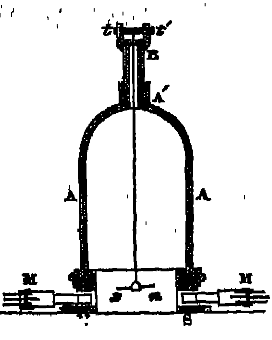
Animal and vegetable substances, after combination, are said to be attracted by the magnet. The flesh, and particularly blood, are acted upon more powerfully than other parts, and bone less powerfully. Burned vegetables have the same property, and also soot, and atmospheric dust; and M. Cavallo has maintained, that brisk chemical effervescence acted upon the magnetic needle.

SECT. II.—*Account of the Experiments of Coulomb, Becquerel, Arago, and Seebeck, on the existence of Universal Magnetism.*

These various experiments on the magnetic power of so many classes of bodies, differing essentially in their composition, and in many of which it could not be reasonably supposed that iron existed, led some philosophers to believe that almost all substances gave indications of magnetism. M. Cavallo announced this opinion, but Mr Bennet questioned the accuracy of the experiments, and ascribed the movements observed in the needle to the agitation of the air in the receiver, arising from changes of temperature produced by the proximity of the observer's body, or from other causes.

It was not, therefore, till 1802, that the supposition ot universal magnetism was put to the test of rigorous experiment. The apparatus which Coulomb employed for this purpose is shewn in fig. 21, where A A is a glass receiver perforated at its top, and having a tube A′B, with a cork B, which could be raised and lowered with facility. Through this cork passed a cord *t t* of wood or metal, to which was attached a silk fibre, which suspended a ring of very fine paper, on which the small needle *n s* (about the third of an inch long and $\frac{1}{30}$th thick) was placed. The receiver was

Fig. 21.



then placed so as to enclose the opposite poles N S of the powerful magnets M M, each formed of four bars of steel tempered to a white heat. Each bar was seventeen inches long, three-fifths of an inch wide, and one-sixth of an inch thick, each bundle of four bars being one and three-eighths of an inch wide, and one-third of an inch thick. The distance N S of their poles was eight tenths of an inch. In making the experiments, the rod *t t* was turned till the needle *n s* was removed from the influence of the magnets; and after the number of its oscillations was observed, the rod *tt* was turned till the needle descended between the poles N S of the magnets, when the number of oscillations of the needle was again counted, or the time in which a given number of oscillations was performed. If the needle performed the same number of oscillations in the same time, whether it oscillated between the poles N S, or beyond their influence, it is obvious that the magnets exercised no power over them; but this was never the case, and Coulomb found that all substances whatever, when formed into small needles, turned themselves in the direction of the poles N S, and, after a few oscillations, finally settled in that position. When these bodies were moved a very little way out of their position of equilibrium, they immediately began to oscillate round it, the oscillations being always performed more rapidly in the presence of the magnets than when they were removed out of their influence. Gold, silver, glass, wood, and all substances, whether organic or inorganic, thus obey the power of the magnets. Hence we cannot avoid the conclusion, either that all bodies are susceptible of magnetism, or that they contain minute quantities of iron, or other magnetic metals, which give them that susceptibility. M. Biot does not consider this alternative so inevitable as it appears, and throws out the conjecture, that the action may not be magnetic, but may be owing to some small force similar or analogous to

the electrical forces developed by the simple contact of heterogeneous bodies. This no doubt might be, if there was any contact; and, in the absence of any reasons whatever for ascribing the observed effects to another cause, we cannot but rest between the alternative opinions above mentioned, giving a preference to that which ascribes the phenomenon to the existence in all bodies of a slight susceptibility to magnetic action.

This opinion derives considerable support from the experiments made by Coulomb on the comparative magnetic susceptibilities of cylindrical needles of gold, silver, lead, copper, and tin, which had been purified with the greatest care by MM. Sage and Guyton, and the results of which we have already given in our history of magnetism. M. Coulomb made a number of experiments on the effects experienced by needles of white wax, containing different proportions of iron filings, and he found that the intensities of the action which they experienced when oscillating between two magnets, was proportional to the absolute quantities of iron which they contained, the distribution and chemical state of the ferruginous particles being the same.

Since the time of Coulomb, methods different from his have been employed in developing magnetism in all bodies whatever. In order to detect small quantities of iron in minerals, M. Haüy employed the process of what he calls *double magnetism*. For this purpose, he placed a small bar-magnet in the direction of the needle, and in the same horizontal plane, the two similar poles being placed towards each other. The magnet being now brought slowly towards the needle, the latter deviates from the direction of the magnetic meridian, and takes a position perpendicular to it, — an effect arising from the combined action of the poles of the magnet and the earth upon the magnetism of the needle. In this position, *a very feeble magnetic action* is sufficient to make the needle turn

round and place its south pole opposite the north pole of the needle.

When the magnet is above the plane of the needle, and their opposite poles placed near each other, the needle does not change its direction while the point of suspension is beyond the bar, and at a suitable distance; but it is not so when the distance changes, for it tends continually to place itself perpendicular to the line of the poles.

This important subject has been investigated by M. Becquerel, who obtained the following results.* His bar-magnet consisted of six united bars, each eight decimetres long and two centimetres broad. The needle was placed at different heights within and without the bar, and he sought to determine for each height the horizontal distance from the point of suspension (which is always in the line of the poles) to the nearest extremity of the needle, in order that its direction might be perpendicular to that line. The results were as follow:

Vertical Distances from the Centre of Suspension to the Bar.	Horizontal Distances of the Centre of Suspension to the extremity, in order that the Needle might take a perpendicular position.
Millimetres.	Millimetres.
100	60 within
150	55
200	46
250	23
300	12
350	45 without
400	82

Hence it appears, that when the centre of suspension is above the bar, the perpendicular position is obtained by increasing the vertical and diminishing the horizontal

* *Traité Exp. de l' Electricité, &c.* tom. ii. p. 387.

distance; and that both these distances are increased while the centre of suspension is below the bar; and the direction of the deviation depends on accidental causes, and is often determined by the simple motion of the apparatus.

When M. Becquerel substituted for his magnetic needle a needle of soft iron, the results were exactly the same, differing only in their intensity. We come now to the original part of M. Becquerel's inquiry. Instead of a needle, he used a small paper case filled with *deutoxide of iron*, or a mixture of deutoxide and tritoxide. With the former the effects were the same as with the steel needle; but it was different with the latter, in which one part of deutoxide was mixed with thirty parts of tritoxide.

If the centre of suspension be placed as near as possible to the north pole of the bar-magnet, and in the line of the poles, the paper case will take immediately a direction perpendicular to this line, instead of one coincident with it, as a soft iron needle would have done. If we put it out of this direction, it will return to it by a series of oscillations, whose velocity depends on the quantity of the deutoxide. From this it follows, that *all the south polar magnetism of the paper case is situated on the side of it next the bar-magnet, while the north polar magnetism is on the other side*, as may be exhibited by carrying a small magnetic needle along the paper case. Such a distribution of magnetism is impossible in soft iron or tempered steel.

If the centre of suspension be above the bar, the paper case will deviate from the position which it had at first, and tend to place itself in the direction of the line of the poles; an effect quite opposite to that produced by a steel or iron needle. The following were the experimental results:

Vertical Distances of the Centre of Suspension from the Bar.	Horizontal Distances of the same Centre to one of the Extremities of the Bar.	Deviations of the Paper Case from the Direction perpendicular to the Line of the Poles.
10 millimetres,	5	24°
	10	44
	15	60
	20	78
	25	78
	30	84
20 millimetres,	5	50
	10	65
	15	78
	20	77
	30	82
30 millimetres.	5	70
	20	76
	30	82

The *transverse magnetism* acquired by the paper case is permanent for some time, however small may be the proportion of deutoxide which it contains.

M. Becquerel next filled the paper case with very pure tritoxide, obtained by calcining nitrate of iron. The effect was much weaker than before. When the point of suspension was very near one of the extremities of the bar, the paper case still placed itself in a position perpendicular to the line of the poles; but if this point was placed above or below the bar, changing at the same time the vertical distance, the paper case deviated from its primitive direction, without, however, taking a direction perpendicular to that which it commonly takes when the centre of suspension is very near the extremity. It might be possible, M. Becquerel thinks, to attain the perpendicular direction by employing much stronger magnets. The following were the experimental results :—

Vertical Distances from the Point of Suspension to the Bar.	Horizontal Distances of the same Point from the end of the Bar.	Deviations from the Direction perpendicular to the Line of the Poles.
	Without the Bar.	
5 millimetres,	5	25°
	10	34
	15	48
	20	55
	25	70
10 millimetres,	5	32
	10	37
	15	43
	20	46
	25	40
	Within the Bar.	
5 millimetres,	10	26
	15	—
	20	45
	25	51
10 millimetres,	10	20
	15	30
	20	45
	25	50

Whenever the tritoxide contains the smallest quantity of the deutoxide, the velocity of the oscillations increases very powerfully. If, for example, we take *two* paper cases, one filled with tritoxide, and the other with tritoxide mixed with one-thirtieth of the deutoxide, the first will perform twelve oscillations in thirty seconds, round a direction perpendicular to the line of the poles, while the other will execute twenty-five in the same time. Hence we may by this means readily determine the quantity of the deutoxide of iron contained in the tritoxide.

M. Becquerel next employed needles of wood, gum-lac, and other substances, which have still a feebler magnetism than the tritoxide of iron. He placed a needle of white wood, *n s*, four centimetres long and two millimetres in

diameter, above the interval between the opposite poles of two bar-magnets, as in fig. 21, the distance between N and S being three or four millimetres. The point of suspension was as near as possible to N S. The needle placed itself perpendicular to the line of the poles N S, in place of the position observed by Coulomb, coincident with N S. It comports itself therefore like the mixture of deutoxide and tritoxide of iron, or like the tritoxide alone. But if we separate gradually the extremities N S of the bars, the wooden needle will place itself in the line N S, joining the poles, as shewn in the figure. The deviations were as follow:

Distances of N S.	Deviations of the Wooden Needle from the perpendicular position.
3 or 4 millimetres,	0°
10	18
20	36
30	56

When the bars are very close, and the needle in the perpendicular position, if we draw it out of this position, and keep it some instants in the direction of this line, it will remain there; but the smallest motion will cause it to return into its primitive direction, which it takes in preference to any other.

If we use only one bar-magnet, and place the wooden needle precisely opposite one of its poles, and as near as possible to the end of the bar, it will still direct itself perpendicularly to it; but if, while the point of suspension remains always in this line, we advance it within the bar, the needle will deviate from its direction, without, however, reaching the position of 90°, as will be seen from the following results:

Distances of the Centre of Suspension from the extremity of the Bar.	Deviations of the Wooden Needle.
5 millimetres,	12°
10	18

Beyond ten millimetres the deviations increase insensibly and irregularly, so that they cannot be measured.

From these interesting experiments, M. Becquerel concludes that the magnetic effects produced by a strong bar-magnet upon a magnetic needle, or one of soft iron, differ essentially from those which take place in all bodies where the magnetism is very weak. In the former, whatever be their positions and directions, the magnetism is always distributed in the direction of their length, to the exclusion of every other direction; whereas in the tritoxide of iron, wood, and gum-lac, it is distributed in a direction which depends on the distance of the body from the poles of the magnet, so that the distribution varies with the direction which the magnet causes these needles to take, in virtue of the action which it exercises over them.

The universal prevalence of magnetism in all bodies whatever has been established by a beautiful discovery of M. Arago. This distinguished philosopher conceived the idea of studying the oscillations of a magnetic needle when placed above or near any body whatever. Having suspended a magnetic needle above metal, or even water, and caused it to deviate a certain number of degrees from its position, it began, when left to itself, to oscillate in arcs of less and less amplitude, as if it had been placed in a resisting medium; and, what was peculiarly curious in these experiments, this diminution in the amplitude of the oscillations did not alter the number of oscillations which were performed in a given time. The following were some of M. Arago's experiments with *water*, *ice*, and *glass*, the semiamplitude of the oscillations being at the instant 43° : —

The distance of the water from the needle
was . . . . . 0·65 millim.
The amplitude lost 10° in . . . 30 oscillations.
When the distance was . . . 5·2 millim.
A loss of 10° of amplitude required 60 oscillations.

That is, the number of oscillations required to diminish the amplitude 10° was twice as great when the distance of the needle from the water was 52·2 millimetres, as when it was 0 65.

By placing the same needle upon ice, M. Arago obtained the following results:

Distances of the Needle from the Ice.	Diminution of the Amplitude.	Number of Oscillations by which this diminution was effected.
Millimetres.		
0·70	From 53° to 43°	26 oscillations.
1·26	From 53 to 43	34
30·50	From 53 to 43	56
52·20	From 53 to 43	60

By placing another needle near a plate of crown glass, he obtained the following results:

0·91	From 90° to 41°	122
0·99	From 90 to 41	180
3·04	From 90 to 41	208
4·01	From 90 to 41	221

Plates of metal afforded M. Arago similar results; but he nevertheless observed that those metals which act with more energy than glass, wood, &c. have a mode of action different from that of these substances. From all these results, it is manifest that all bodies, when placed near a magnetic needle in a state of oscillation, exercise over it an action, the effect of which is to diminish the amplitude of its oscillations, without altering their number; and hence the doctrine of the universal prevalence of magnetism in all bodies derives a new confirmation.

When Dr Seebeck of Berlin heard of the discovery of M. Arago, he made a magnetic needle two and an eighth inches long oscillate at a distance of three lines above plates of various bodies, and counted the number of oscillations which were required in each case to reduce the amplitude from 45° to 10°.

Substances employed.	Thickness of the Plates.	Number of Oscillations of the Needle.
Marble	0·0 line	116 oscillations.
Mercury	2·0	112
Bismuth	2·0	106
Platina	0·4	94
Antimony	2·0	90
Lead	0·75	89
Gold	0·2	89
Zinc	0·5	71
Tin	1·0	68
Brass	2·0	62
Copper	0·3	62
Silver	0·3	55
Iron	0·4	6

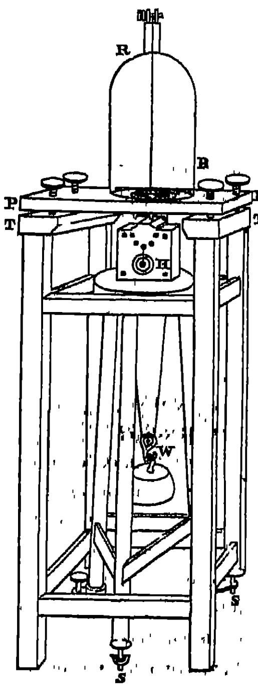
Dr Seebeck found, that in alloying magnetic with non-magnetic substances, he formed *compounds which exercised no action on the magnetic needle.* The alloys which had particularly this singular property, were those consisting of four parts of antimony and one of iron, or two parts of copper and one of nickel. In these cases, the magnetism of the two ingredients must have been neutralized by their opposite actions.

CHAPTER IV.

ON THE DEVELOPMENT OF MAGNETISM IN ALL BODIES BY ROTATION.

WHEN M. Arago was engaged in the experiments described in the preceding chapter, the idea occurred to him of trying if the magnetic needle would be dragged along by the rotatory plates which had the power of diminishing the amplitude of its oscillation. This happy conjecture was immediately confirmed by experiment, and one of the most beautiful discoveries added to the science of magnetism.

Fig. 22.



The apparatus which he used for this purpose is shewn in fig. 22, where H is a clock made of copper, with the exception of two or three pivots, which are of steel. It is supported on a tripod stand T T, which can be levelled by screws S S at the end of its three feet; and the object of it is to give a rapid rotatory motion by a vertical axis, on which is fitted a piece, *a*,*b*,*c*, fig. 23, with three branches, upon which the revolving discs

are to be placed. These discs are perforated at their centre by a small hole which receives the prolongation of the axis of rotation, and they are kept upon the branches *a*, *b*, *c*, by the pressure of a screw. Wings *w*, *w*, *w*, (fig. 23,) which can be inclined at any angle, are applied for the purpose of retarding the velocity of the discs. A plate, P P, with an opening in its centre, a little larger than the diameter of the discs, rests upon the table T, T, and a sheet of paper, *f*, *f*, shown in fig. 24, (which is an enlarged view of that part of the apparatus,) is pasted to the lower face of P P. A glass receiver R R rests upon the upper face of P P, and within it is suspended the magnetic needle *a a′*, by a fibre of silk attached to the axis and button *m n*, by which the needle can be raised or depressed. A weight W gives motion to the clock, and a hand indicates upon the dial-plate the number of revolutions performed by the disc in a given time.

Fig 23.

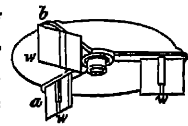
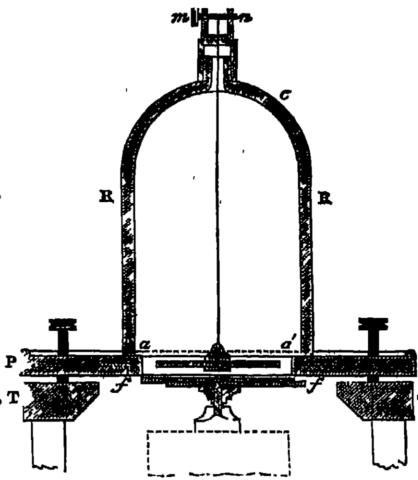


Fig. 24.



When a disc of copper was placed on the support *a*, *b*, *c*, fig. 23, as shown at P P, fig. 24, and the copper made to revolve beneath the needle *a a′*, with the sheet of paper

ff intervening, the needle $a\ a'$ is drawn out of the magnetic meridian the instant that the copper begins to revolve, and with a degree of force proportional to the velocity of rotation. As the force with which the needle is dragged from its place is opposed to the magnetic action of the earth, which tends to keep the needle in the magnetic meridian, the needle will take a position of equilibrium depending on the ratio of these forces. When the motion of thé copper disc, however, is very rapid, the magnetism of the earth is overpowered by that of the revolving plate, and the needle does not stop, but continues to turn. The action of the revolving disc decreases in proportion as the distance of the needle from the plate P P is increased, the velocity being the same; so that if the motion of the needle be continuous when the two bodies are separated only by a sheet of paper, the needle will take a fixed position by increasing its distance from the plate; and its deviation from the magnetic meridian becomes less and less as it is removed to a greater height above the disc. When the plates have portions cut out in the direction of their radii, their action on the needle is diminished.

In trying plates of various metals, M. Arago found the results so dependent on the alloy which the metals contained, that he did not publish the results which he obtained. He devoted his attention to the determination of the directions of the force which is developed in the revolving discs, and for this purpose he sought the components of this force in the direction of three lines parallel to three co-ordinate planes perpendicular to each other. The *component* perpendicular to the plate he found to be a repulsive force, which may be rendered sensible by means of a very long magnet suspended by a thread vertically to the extremity of the arms of a balance kept in equilibrium by a weight at the other extremity. The moment that the plate begins to revolve, the magnet is

repelled, and the beam of the balance inclines to the other side. The *second* component is horizontal and perpendicular to a vertical plane which contains the radius abutting against the projection of the pole of the needle. This is the force which gives a motion of rotation to the needle, and it acts in the direction of a tangent to the circle. The *third* component is parallel to the radius which abuts against the projection of the pole of the needle. It may be determined with a dipping needle placed vertically, so that its axis of rotation is continued in a plane perpendicular to one of the radii of the disc. A similar needle placed at the centre of the disc experiences no action. There is also a second point, nearer the margin than the centre, where a needle experiences no change in its position; but between these points the lower pole is constantly attracted towards the centre, while it is repelled beyond that point.

No sooner were M. Arago's experiments announced to the Institute, which was done at the sitting of the 7th March, 1825, than philosophers in every part of Europe repeated them, and succeeded in adding several important facts to those discovered by M. Arago. MM. Babbage, Herschel, Barlow, Nobili, Baccelli, Christie, and MM. Prevost and Colladon, took a prominent part in these researches. The results obtained by Messrs Babbage and Herschel were the most important, and the experiments were made in a manner different from those of M. Arago. A horse-shoe magnet, which lifted twenty pounds, was made to revolve rapidly round its axis of symmetry, placed vertically, with its poles uppermost. A circular disc of copper, six inches in diameter and $\frac{1}{24}$th of an inch thick, was suspended above the revolving magnet. As soon as the rotation of the magnet commenced, the copper began to turn in the same direction, at first slowly, but afterwards with an increasing velocity. When the magnet was made to turn in the opposite direction, the disc of

copper changed the direction of its motion also, and exhibited the same phenomena. Metallic plates, ten inches in diameter and half an inch thick, when interposed between the magnet and the copper disc, did not sensibly modify the results, as M. Arago had observed. Glass produced no effect, but a sheet of tinplate iron diminished greatly the influence of the magnet, while two such plates almost destroyed it. They also found that a disc of copper ten inches in diameter, and half an inch thick, and revolving with a velocity of seven revolutions in a second, did not communicate any motion to a similar disc freely suspended above it.

In comparing the influence of different metals, each disc had the same diameter and the same velocity; and the following were the results which were obtained by this and another method of observation:—

	Ratio of the Force to that of Copper.	Ratio by another Method.
Copper,	1·00	1·00
Zinc,	0·90	1·11
Tin,	0·47	0·51
Lead,	0.25	0·25
Antimony,	0·11	0·01
Mercury,	0·00	0·00
Bismuth,	0·01	0·00
Wood,	0·00	0·00

The second method of observation by which the results in the last column were obtained was more expeditious than the first. Portions of different bodies of the same form and dimensions were suspended above a revolving magnet, and the time of successive oscillations and the points of equilibrium were observed.

Our authors next sought to determine the effect produced by a solution of continuity in the metallic disc upon which the revolving magnet acted. For this purpose a

disc of lead twelve inches in diameter and one-tenth of an inch thick, was suspended at a given distance from a horse-shoe magnet revolving with the ordinary rapidity, first in its entire state, and afterwards in the state shewn in the annexed figures, the black lines in the direction of the radii being the planes where the lead was cut through.

Fig. 25. Fig. 26. Fig. 27.

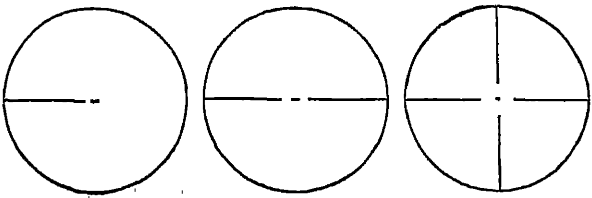
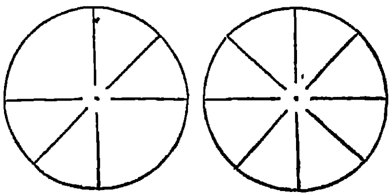


Fig. 28. Fig. 29.



The accelerating forces, represented by $\frac{s}{t^2}$, where s is the number of the revolutions, and t the time employed, are as follow:—

Uncut Disc.	Disc as in fig. 25.	Disc fig. 26.	Disc fig. 27.	Disc fig. 28.	Disc fig. 29.
1258	1047	913	564	432	324

Effects similar, but differing in degree, were obtained with other metals. With soft tinned iron the cutting produced a very slight diminution of effect, whilst in copper the same operation reduced the accelerating force in the ratio of five to one.

Messrs Babbage and Herschell next tried the effect of

filling up the cuts with other metals. A light upper disc, suspended at a given distance above a revolving magnet, performed six revolutions in 54″·8. When it was cut as in fig. 29, its magnetic action was so weakened that it took 151″·3 to perform six revolutions. When the eight open radial spaces were filled up with tin, its magnetic action was restored to such a degree that it made six revolutions in 57″·3. This fact is very interesting, as tin has less than half the energy of copper. The following results were obtained from other experiments, the numbers representing the accelerating forces or the magnetic energies developed in the plates :—

Brass not cut	1·00
Brass cut	0·24
Brass soldered with bismuth	0·53
Brass soldered with tin	0·88
Copper not cut	1·00
Copper cut	0·20
Copper soldered with tin	0·91

In determining the law of the force in relation to the distance, Messrs Babbage and Herschel found it to vary between the ratio of the square and the cube of the distance. Mr Christie found, that when the revolving disc was thick and the needle delicate, the force which produced the deviation of the needle increased directly as the velocity of rotation, and inversely as the fourth power of the distance. MM. Prevost and Colladon found that the angles of deviation, and not their sines, increased in the direct ratio of the velocity, at least within certain limits; and that the sines of the angles of deviation were in the inverse ratio of the two and a half power of the distance.*

M. Haldat made some interesting experiments on this subject. He found that every needle, however weak was its magnetism, obeyed the action of the revolving disc;

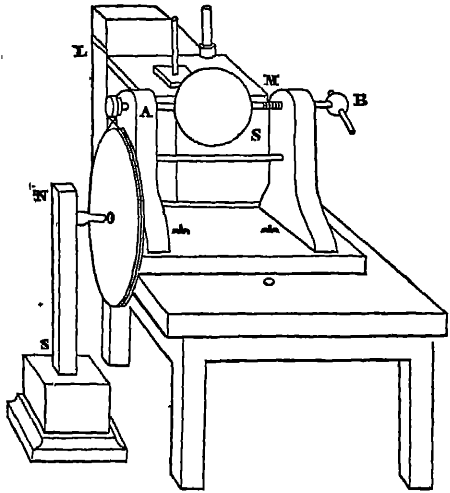
* *Bibl. Univers.* tome xxix. p. 316.

but that this action disappeared entirely when its polarity disappeared. He found it impossible to magnetize needles by the action of the revolving disc, however rapid; and, in consequence of ascribing this effect to the want of coercive power, he employed discs of iron and steel, both soft and hardened.

A disc of soft iron acted with more energy than one of copper, and with the same velocity it dragged the needle twice the distance that a disc of brass did. Iron strongly hammered acted like soft iron, and was unable to give polarity to a steel needle. But a disc of untempered steel one twenty-fifth of an inch thick did not produce any appreciable effect on the magnetic needle, which, after a few irregular oscillations, maintained its ordinary position of equilibrium. Hence our author concluded that the force which acted upon it was in the inverse ratio of the coercive force. M. Haldat also found that discs in a state of incandescence exercised the same action as those at the ordinary temperature.

We have already seen, in our historical detail, that about six months previous to the announcement of M. Arago's discoveries, Mr Barlow had announced to the Royal Society of London the result of a series of experiments on the magnetic effects produced by iron in rotation. Having found that an iron ball performing 640 revolutions in a minute caused a magnetic needle to deviate several degrees, and to take a fixed position during the continuance of the motion; that the needle deviated in an opposite direction when the motion of the ball was reversed; that there were certain positions in which a bomb twelve inches in diameter, moved by a steam-engine, occasioned no deviation in the needle; that in some positions the deviation was in one direction, and in other positions in another; and that the deviation varied between 0° and 80°; he constructed a regular apparatus for determining the laws of these phenomena, and in which the iron which formed part of it should not influence the

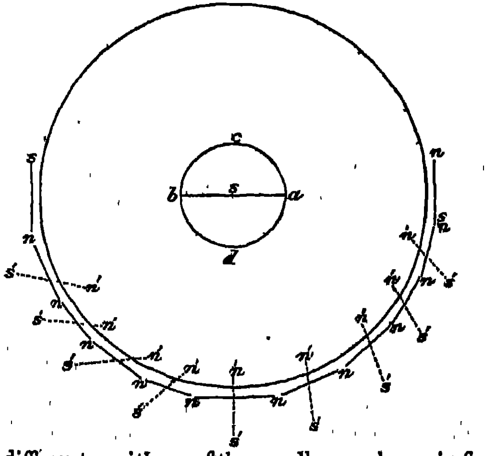
Fig. 30.



results. This apparatus is shewn in fig. 30, where S is an iron sphere, made to revolve on a horizontal axis AB, by means of two wheels, like an electrical machine, their diameters being as six to one, so as to perform 720 revolutions in a minute. A table LM was placed near the sphere, for holding the needle, so that the needle could be placed in any position, either above or below the sphere. The table LM being brought to the height of the axis AB, the needle was placed successively in different positions round the sphere. The influence of the earth's magnetism on the needle being destroyed or neutralized by the action of a magnet properly placed for this purpose, and shewn at NS standing vertically, Mr Barlow found, that whatever was the azimuth of the needle, its *north pole* approached the sphere S when the upper part of the sphere was moving *towards* the needle, and that its *south pole* approached the sphere when the upper part moved *from* the needle.

Having placed the axis of rotation sometimes in the magnetic meridian, sometimes in the direction of east and west, and sometimes in intermediate positions, he found, that whatever was the direction of the axis of rotation, the needle being always a tangent to the sphere, the *north* end of the needle was *attracted* when the sphere moved *towards* the needle, and *repelled* when its motion was *from* the needle. When the needle was carried round the revolving sphere in the semicircle, where the motion was directed towards the needle, its *north* extremity *approached* the sphere, and in the other semicircle *receded* from it. The points where the sphere exercised upon it no action were at the two extremities of the axis, and those where the effect was a maximum were at the two extremities of an axis at right angles to this. In this case the direction of the needle was towards the centre of the ball.

Fig. 31.



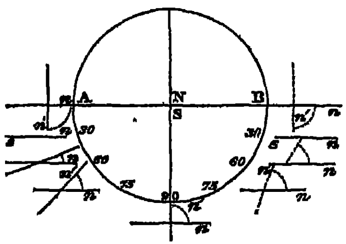
The different positions of the needle are shewn in fig. 31, where *s* is the sphere, *a b* its axis of rotation, and *cd* its equator. The lines *ns*, *ns*, &c. shew the primitive

position of the needle, and the dotted lines *n′s′*, *n′s′*, &c. those assumed by it when the motion is made from *c* to *d*. The effects are reversed when the motion is made from *d* to *c*.

If we carry the needle, when perfectly neutralized, round the sphere, and parallel to its axis, it has a tendency to place itself at right angles to the axis, and takes opposite directions at certain parts of the circle. If, for example, the axis be in the magnetic meridian, and the motion directed from the west to the east point of the horizon, the needle will direct itself to the west, and will do the same at all points between the horizon and an altitude of 60°. Beyond this the north end will direct itself to the east till it has passed the zenith 30° to the west; and that from this point to the west horizon, the north extremity will direct itself to the west, and similar changes will take place under the sphere. The same effects are produced, whatever be the direction of the axis and that of motion.

When a magnetic needle *not neutralized* is placed in different positions round the sphere whose axis is in the magnetic direction, the effects produced are as shewn in fig. 32, where AB is the axis of rotation, the black lines

Fig. 32.



representing the natural deviations of the needle, and the dotted ones those which it assumes when the sphere is

in motion. Beginning at the point A, if the motion be from left to right, that is, from west to east, the needle moves from n to n' in the same direction till it arrives at 30°. It then remains in its natural direction. The needle moves in a contrary direction from right to left at 60°, 75°, and at 90°.

Mr Barlow was next desirous of ascertaining the different effects produced by a solid and a hollow ball of iron, and with this view he put in motion a solid ball 7·87 inches in diameter, and weighing sixty-eight pounds, and also a hollow sphere of iron, weighing only about thirty-four pounds. Both of them performed 640 revolutions in a minute, and the following were the average results : —

		Weight.
Mean deviation of the solid ball.........	28° 24′......	68 lbs.
Mean deviation of the hollow ball......	15 5	34

When the two balls were at rest, the difference of their action was nothing.

Mr Barlow's paper on rotation was communicated to the Royal Society on the 14th April, 1825, and on the 20th Mr Christie communicated one *On the Magnetism of Iron arising from its Rotation.* Mr Christie's experiments were made with circular plates of iron put in motion by an ingenious piece of machinery, by which he could make the plate revolve in every possible plane in reference to the magnetic meridian. From a great body of well-devised experiments, he obtained the following general law of the deviation due to rotation, so that the direction of the rotation being given, he could tell the direction of the deviation. This law we must give in his own words.

"I refer the deviations of the horizontal needle to the deviations of magnetic particles in the direction of the dip, or to those of a dipping needle passing through its centre; so that, in whatever direction this imaginary

dipping needle would deviate by the action of the iron, the horizontal needle would deviate in such a manner as to be in the same vertical plane with it: thus, when the north end of the horizontal needle deviates towards the west, and consequently the south end towards the east, I consider that it has obeyed the deviation of the axis of the imaginary dipping needle, whose northern extremity has deviated towards the west, and its southern towards the east; so that the western side of the equator of this dipping needle has deviated towards the south pole of the sphere, and its eastern side towards the north pole. It would follow from this, that if the north and south sides of the equator of the dipping needle (referring to these points in the horizon) deviated towards the poles, no corresponding deviations would be observed in the horizontal needle; the effect, in this case, taking place in the meridian, would only be observable in the angle which the dipping needle made with the horizon. As it is not my intention at present to advance any hypothesis on the subject, I wish this to be considered only as a method of connecting all the phenomena under one general view. Assuming it then for this purpose, it will be found that the *deviations of the horizontal needle due to rotation* are always such as would be produced *by the sides of the equator of this imaginary dipping needle deviating in directions contrary to the directions in which the edges of the plate move,* that edge of the plate nearest to either edge of the equator producing the greatest effect on it."

From another set of experiments, Mr Christie also found that the effect produced on the iron by its rotation is permanent so long as the plate remains stationary; that it is independent of friction; that it is so far independent of velocity, *that the iron can scarcely be moved so slowly that the whole effect shall not be produced; and that the whole effect is produced by making it perform one-fourth of a revolution.* After Mr Christie had discovered these

peculiar effects, he exhibited some of the phenomena to Mr Barlow, who conceived that the effect would be increased by rapid rotation, and who was thus led to make the experiments of which we have already given an account; but the phenomena differ essentially from those observed by Mr Christie, the former being temporary and dependent on velocity, while the latter are permanent, and independent of the rapidity of rotation.

In comparing the magnetic forces produced by rapid and slow rotation, Mr Christie found that the forces exerted on the needle during the rapid rotation of the plate are always in the same direction as the forces which are derived from the slowest rotation, and which continue to act after the rotation has ceased; but that the former forces are greater than the latter. From a mean of all the observations, the forces seem to be in the ratio of seventeen to thirteen, or very nearly of three to two. Hence Mr Christie conceives that the polarizing of the iron in the same direction will account for the phenomena in both cases; but that the intensity of the polarity during the rapid rotation is greater than of that which appears to be permanent after the rotation, whether slow or rapid, has ceased; and that the phenomena observed during rapid rotation are such as should be expected from what have been described as arising from rotation, without regard to its velocity.

We have already seen that Messrs Babbage and Herschel interposed plates of various metals between the revolving magnet and the copper disc, and found no perceptible effect to be produced. Mr Snow Harris,* however, has recently shewn that several substances not supposed to contain iron have the power of intercepting the influence of a revolving magnet. A circular magnetic disc being delicately balanced on a fine central point by means of a rim of lead, was put into a state of rotation

* *Phil. Trans.* 1831, p. 497.

on a small agate cup, at the rate of 600 revolutions in a minute; and a light ring of tinned iron, also finely balanced on a central pivot, was placed immediately over it, at about four inches distance, by means of a thin plate of glass, on which its pivot rested. When the ring of tinned iron began to move slowly on its pivot by the influence of the magnet revolving below, a large mass of *copper*, about *three* inches thick, and consisting of plates a foot square, was carefully interposed between the magnet and the iron ring. The interposition of the copper soon sensibly diminished the motion of the iron disc, and at length *arrested it altogether*. On again withdrawing the copper, the motion of the disc was restored; and the same effects were repeatedly obtained. In this experiment both the magnet and the disc were enclosed by glass shades, and supported on a firm base.

The same effects were produced by a mass of silver and zinc; but when their thickness was considerably diminished by removing the central plates, the motion of the disc was not impeded. A very great thickness of *lead* was necessary to stop the disc, in consequence, as Mr Harris supposes, of its magnetic energy being so much less than that of copper.

CHAPTER V.

ON THE INFLUENCE OF HEAT ON MAGNETISM.

THIS interesting department of magnetism divides itself into three parts : — 1*st*, On the effect of heat on the development of free magnetism ; 2*dly*, On the anomalous attraction observed during the bright red and red heats ; and, 3*dly*, On the effect of heat on the distribution of magnetism in magnets.

SECT. I.—*On the Effect of Heat on the development of Magnetism in Cast and Malleable Iron.*

In the course of his experiments on the relative magnetic powers of different kinds of iron and steel, already given in the history of magnetism, Mr Barlow was led to the conclusion, that the harder the metal was, the less it exhibited of a magnetic quality,—a result which was highly favourable to the hypothesis, that the cohesive power of hardened steel not only prevented the entire development of its magnetism, but also the re-combination of the two kinds of magnetism when they were displaced by the action of a powerful magnet. With the view of establishing this hypothesis, Mr Barlow found it necessary to ascertain whether these different kinds of iron and steel would exhibit the same magnetic powers when reduced to the same degree of softness, which could only be done by heating them in a furnace, and trying their magnetic qualities in that state.

Having procured a bar of soft iron twenty-five inches long and an inch and a quarter square, and a cast-iron

one of nearly the same dimensions, he inclined the bars in the direction of the dip ; and having placed a magnetic needle nearly on a level with the upper extremity, and at the distance of six inches from it, he observed the deviations produced by the bars in different states of heat. Thus,

Cast iron	Cold	Mean deviation	21°	30′
Ditto	White heat	Ditto	0	0
Ditto	Blood-red heat	Ditto	62	0
Malleable iron	Cold	Ditto	40	0
Ditto	White heat	Ditto	0	0
Ditto	Blood-red heat	Ditto	55	0

These experiments were often repeated with the same results. It deserves to be remarked as a singular result, that cast iron is decidedly inferior in its action when cold, and when hot possesses a superior power, to malleable iron.

Mr Barlow now compared malleable iron with soft and hard shear steel. The bars were twenty-four inches long and an inch and a quarter square, and the following were the results :

Malleable iron	Cold	Mean deviation	15°	10′
Ditto	White heat	Ditto	0	0
Ditto	Blood-red	Ditto	41	11
Soft shear steel	Cold	Ditto	11	0
Ditto	White heat	Ditto	0	0
Ditto	Blood-red	Ditto	48	0
Hard shear steel	Cold	Ditto	8	0
Ditto	White heat	Ditto	0	0
Ditto	Blood-red	Ditto	47	30

These experiments establish the curious fact of the total destruction of the magnetic virtue by a *white heat* ; and also the no less important one, that every kind of iron or steel has a greater capacity for developing its magnetism when softened by fire than when cold.

SECT. II.—*On the Anomalous Attraction observed in Cast and Malleable Iron during the Bright Red and Red Heats.*

In pursuing the preceding researches, Mr Barlow was led to observe a remarkable anomaly in the action of the iron at the red heat. When iron brought to a white heat has wholly lost its power, it again acquires, as it passes into the bright red and red, a magnetic power; but, what is truly strange, its power is *attractive* for the south end of the needle; that is, if the *north* pole of the needle was attracted when the iron was cold, the *south* end will be attracted when the iron is at a bright red heat.

In order to investigate this subject thoroughly, Mr Barlow made a very extensive series of experiments with four different bars, each twenty-five inches long and an inch and a quarter square, two of them being of cast and two of malleable iron. He used also other two bars, one of cast and one of malleable iron, of the same dimensions, which were kept as standards to determine the quantity of cold attraction. The time employed in each experiment was a quarter of an hour: the white heat generally continued about *three* minutes when the negative attraction commenced. This attraction lasted about *two* minutes more, when the usual attraction began. This sometimes reached its maximum with great rapidity, but at other times it increased very gradually. The following table contains the results of Mr Barlow's experiments. The letters CB denote the cast-iron bar, and MB the malleable-iron bar: and the sign + indicates when the ordinary attraction of the iron takes place, and — the anomalous or negative attraction.

Table of the Results of Mr Barlow's Experiments on the Effect of Iron on the Compass Needle at Different Degrees of Heat.

N.B.—We have omitted the column for White Heat, as no effect is ever produced at that temperature.

No.	Description of Bar.	Height and Depth of Centre of Bar from Needle.	Distance of Bar from Needle.	Position of Needle.	Effect when *Cold.*	Effect of *Red Heat.*	Effect at *Blood-Red Heat.*	Remarks.
		Inches.	Inches.					
1	C. B. No. 1.	0·0	6·0	S. 80° W.	+ 0° 0′	— 17° 0′	0° 0′	South end drawn to the bar at red heat.
2	M. B. No. 2.	4·5 below.	6·0	Ditto.	+ 30 0	0 0	+ 45 0	
3	C. B. No. 2.	Ditto.	6·0	Ditto.	+ 18 0	0 0	+ 49 0	
4	M. B. No. 1.	Ditto.	6·0	Ditto.	+ 29 30	— 12 0	+ 44 0	
5	Ditto.	1·3 below.	6·0	Ditto.	Not observed.	0 0	+ 52 0	
6	Ditto.	4·5 below.	6·0	N. 80 W.	Ditto.	— 12 30	+ 70 0	This bar being left standing, it attracted the same three days after.
7	Ditto.	Ditto.	6·0	S. 80 W.	Ditto.	— 12 30	+ 30 0	
8	Ditto.	Ditto.	6·0	Ditto.	Ditto.	0 0	+ 25 0	The needle suspected to touch the box.
9	Ditto.	Ditto.	6·0	Ditto.	Ditto.	— 19 0	+ 30 0	
10	Ditto.	1·0 above.	6·0	Ditto.	Ditto.	— 15 0	+ 4 0	
11	M. B. No. 2.	12·5 below.	8·5	N. 80 W.	+ 29 30	0 0	+ 37 30	Observed at the same time with two compasses.
12	Ditto.	Ditto.	8·5	N. 80 E.	+ 30 0	0 0	+ 41 0	
13	C. B. No. 1.	Ditto.	8·5	N. 80 W.	+ 16 0	0 0	+ 42 30	Ditto.
14	Ditto.	Ditto.	8·5	N. 80 E.	+ 15 30	0 0	+ 47 30	
15	M. B. No. 2.	9·0 below.	8·5	N. 80 W.	+ 28 30	— 1 0	+ 39 30	Ditto.
16	Ditto.	Ditto.	8·5	N. 80 E.	+ 29 30	— 1 30	+ 42 0	
17	C. B. No. 1.	Ditto.	8·5	N. 80 W.	+ 15 45	— 1 30	+ 45 0	Ditto.
18	Ditto.	Ditto.	8·5	N. 80 E.	+ 16 0	— 1 30	+ 49 0	
19	M. B. No. 2.	6·0 below.	8·5	N. 80 W.	+ 25 0	— 3 0	+ 32 30	Ditto.
20	Ditto.	Ditto.	8·5	N. 80 E.	+ 26 0	— 3 30	+ 33 0	
21	C. B. No. 1.	Ditto.	8·5	N. 80 W.	+ 11 30	— 3 30	+ 36 30	Ditto.
22	Ditto.	Ditto.	8·5	N. 80 E.	+ 13 0	Not observed.	+ 36 30	

Table of Mr Barlow's Experiments—continued

No.	Description of Bar.	Height and Depth of Centre of Bar from Needle.	Distance of Bar from Needle.	Position of Needle.	Effect when Cold.	Effect of Red Heat.	Effect at Blood-Red Heat	Remarks.
		Inches.	Inches.					
23	M. B. No. 2.	3·0 below.	6·0	S. 80 E.	+ 8 0	— 21 30	Not observed.	Observed at the same time with two compasses.
24	Ditto.	Ditto.	6·0	N. 45 W.	Not observed.	— 25 30	+ 25 30	
25	M. B. No. 1.	0·0	6 0	Ditto.	0 0	— 40 0	0 0	North end drawn to the bar at red heat.
26	M. B. No. 2.	1·0 above.	5·3	N. 60 W.	+ 2 0	— 4 30	+ 5 30	Both attractions very gradual.
27	M. B. No. 1.	Ditto.	5·3	Ditto.	Not observed.	— 12 30	+ 5 30	Passed suddenly to $12\frac{1}{2}^{\circ}$, but returned immediately.
28	M. B. No. 2.	9.0 above.	6·0	N. 85 E.	+ 47 30	— 2 30	+ 60 0	Attractions gradual.
29	M. B. No. 1.	Ditto.	6·0	Ditto.	+ 47 30	— 2 30	+ 60 0	Ditto.
30	M. B. No. 2.	1·0 below.	5·5	N. 45 W.	Not observed.	— 55 0	+ 5 45	Negative attraction rather sudden.
31	M. B. No. 1.	4·5 above.	7·0	N. 75 E.	Ditto.	— 2 30	+ 33 30	Motion of needle very slow.
32	M. B. No. 2.	1·7 below.	5·5	N. 45 W.	Ditto.	+ 100 0	+ 13 30	100° very sudden, returned immediately.
33	M. B. No. 1.	1·7 above.	5·5	Ditto.	Ditto.	— 26 0	+ 13 30	Both attractions gradual.
34	M. B. No. 2.	Ditto.	5·5	Ditto.	Ditto.	+ 30 0	+ 13 30	The same as No. 32; both anomalous.
35	M. B. No. 1.	4·5 above.	6·0	N. 55 E.	Ditto.	— 5 30	+ 35 30	Attractions very gradual.
36	M. B. No. 2.	Ditto.	6 0	Ditto.	Ditto.	— 0 0	+ 35 30	
37	M. B. No. 1.	0 0	4·7	West.	+ 3 30	— 50 0	+ 8 0	Motion regular, but quick.
38	M. B. No. 2.	0·0	4·7	North.	0 0	0 0	0 0	No motion in needle.

One of the most remarkable results of these experiments is, that the anomalous action of the bar between a bright-red and blood-red heat *increases* as we raise the bar above the needle, and becomes a *maximum* at the centre of the bar; whereas at low temperatures the action of a bar of iron under the very same circumstances goes on diminishing as the bar is raised, and becomes a minimum at the centre. When the needle is placed at the height of the centre of the bar, when heated to produce the anomalous effect, the smallest displacement is sufficient to change the sign and the quantity of the deviation.

Mr Barlow made some experiments with a twenty-four pound ball of iron, but the heat was too intense to allow any very accurate observations to be made. The results, however, were as follow:

Cold attraction.........	+ 13°	30′	deviation.
Red heat...............	— 3	30	
White heat..............	0	0	
Blood-red heat.........	+ 19	20	

No effect whatever was produced on the needle by heated bars of copper.

In order to explain the singularly anomalous action above described, Mr Barlow supposes, that during the cooling of the bars, the extremities where this cooling is most rapid become magnetic before the rest of the metal, and that there results from this a complex action. He allows, however, that this supposition does not sufficiently explain all the observed phenomena. The explanation given by Professor Kupffer is more satisfactory. In weakly magnetized bars the points of indifference are very near the extremities; but in Mr Barlow's experiment the magnetism communicated to soft iron by the earth being nothing at a bright-red, and reaching its maximum at a blood-red heat, there is probably formed a point of indifference at each extremity of the bar. If this is the case,

the raising of the bar places the needle in front of points which are beyond the point of indifference, and which possess a magnetism opposite to that of the extremity itself. At the first epoch of cooling, this opposite magnetism should even increase to a certain point, and the more as we approach the middle of the bar; but in proportion as the magnetism of the bar increases, the point of indifference will approach its middle, and the phenomena of ordinary attraction re-appear.

Sect. III. — *On the Effects of Heat on the Distribution of Magnetism in Magnets.*

M. Coulomb was the first philosopher who investigated the important subject of the influence of heat on the distribution of magnetism in needles and magnets.* He took a bar of steel 162 millimetres long, fourteen wide, and weighing eighty-two grammes. This bar was brought to a cherry-red heat, about 900°, and cooled slowly in the air, so as to have no temper. It was then magnetized to saturation at the temperature of about 12° Reaumur. In this state the time of making *ten* oscillations was observed. Its temperature was again raised successively so many degrees, and, after being cooled, the time of performing ten oscillations was again measured. The following were the results:

Temperature in degrees of Reaumur.	Time of performing Ten Oscillations.
12°	93″
40	97·5
80	104
211	147
340	215
510	290
680	very great.

* Biot, *Traité de Physique*, tom. iii. p. 106.

Hence it is obvious that the magnetic intensity of the bar diminishes rapidly as its temperature is raised.

From another set of experiments Coulomb concludes that the tempering of a bar previous to its being magnetized has no influence until the heat at which it is tempered becomes about 750°. When the tempering is at 900°, the bar will take double the magnetic force that it did at 12°; the ratio of the time of ten oscillations being 63″ and 93″, the squares of which, to which the magnetic forces are proportional, are nearly as one to two.

After the magnet had received the hardest temper at 950°, it was magnetized to saturation. When it was brought back, by annealing, to lower temperatures, and again magnetized, the effects were as follow:

Temperature.	Time of *Ten* Oscillations of a Bar tempered at 95°.
12°	63″
80	66
214, blue colour	80
410, colour of water	170

Hence we see that the progressive rise of temperature alters the magnetism of the bar much more when it had been first tempered towards 900° and cooled slowly, than when it had been first put into the annealed state.

When in the annealed state the bar is exposed only to temperatures below 500°, it receives its original force by being again magnetized; but in the state of temper it is not so. Each rise of temperature diminishes perceptibly the magnetic force which the bar can receive from being again magnetized. This is shewn in the following table:

Annealing Temperature.	Time of performing Ten Oscillations when again magnetized.
12°	63″
214	64·5
410, colour of water	70
900, cherry red	93

The bar, therefore, attained its maximum energy when tempered at 900°. It then performed ten oscillations in 63″. Setting out from this term, the directive force diminished in proportion as the annealing temperature increased. At 900° the bar, magnetized anew to saturation, employed 93″ to make ten oscillations, as in the first experiments, which ought to have been the case, as it was brought back to the same state of perfect annealing from which it was at first taken.

The bars used by Coulomb were about thirty times as long as they were thick, and with such bars similar results were always obtained. But this was not the case with larger bars. Having taken a steel wire 326 millimetres long and four in diameter, he tempered it at 820°, magnetized it to saturation, and determined its directive force. He repeated the same operation after having annealed it at different temperatures, and the following were the results:

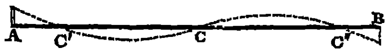
Annealing Temperature.		Time of Ten Oscillations.
12°	temperature of atmosphere	89″
320	colour of water	75
450	deep red	68
530	less deep red	70
900	bright cherry red	76

Here the hard temper gives the weakest directive force, as we have already seen in the preceding experiments. The maximum effect takes place when the wire is annealed at about 450°, and this result is a general one for all wires and plates whose length is very great relative to their width.

This result seems to be connected with a particular mode of distribution of free magnetism. In bars whose length does not exceed thirty times their diameter, there is never more than one magnetic centre, which is in the middle of the bar. But when the ratio of the length to

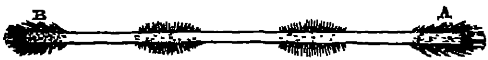
the breadth is greater than this, magnetizing it produces always three centres, one in the middle of the bar, and the other two at equal distances from its extremities. This effect is shewn in fig. 33, and in fig 34. The effect of

Fig. 33.



placing such a magnet in iron filings is shewn in fig 34; and in fig. 33 the curve of the intensities is seen to cross

Fig. 34.



the axis between the centre C and the poles A B, the two new centres being at C′ and C″.

M. Coulomb found that the distance C′ A, C″ B, of the two new centres from the extremities of the magnet, varies with the temper; and the annealing heat is shewn by the following results, obtained with a wire-magnet 326 millimetres long:—

	Time of Ten Oscillations.	Distances of the Centres C′ C″ from the Centre C, the Middle of the Magnet.	
		C′.	C″.
Hard temper	89	98	98
Annealed at the colour of water	75	63	63
Ditto at dark-red heat	68	43	43
Ditto at cherry red	76	0	0

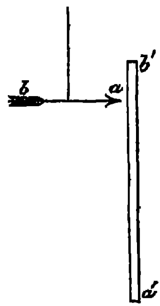
In proportion as the annealing heat increases, the two centres C′ C″ approach each other, and are re-united with the centre C at a cherry-red heat. This last result is very important in the construction of compass-needles. Coulomb regards the *dark red* as the best annealing heat for needles or bars whose length exceeds thirty times their

thickness, and the state of hard temper for those where the ratio between the length and the thickness is less.

It is extremely probable, as M. Biot supposes, that when magnets are larger in proportion to their thickness than those used in the preceding experiments, a greater number of centres will be produced, were it from no other cause than the re-action of the plate upon itself.

In examining the influence of temperature on magnets, Professor Kupffer began by examining the effect of heat in altering the distribution of magnetism. For this purpose he took a parallelopiped of tempered steel, 503 millimetres long, 15½ wide, and 5 thick, and having magnetized it to saturation, he heated it, and allowing it to cool slowly, he submitted it to examination. The magnet was placed vertically, as at *a′ b′*, and a needle, suspended by a silk fibre, was made to oscillate before any point *a b*, in order to determine the intensity of magnetism at that point. In this way he obtained the following results:

Fig. 35.



Distance *a b′* in Millimetres.	Magnet not heated. Magnetic Force.	Same Magnet heated to 80°, and examined after cooling. Magnetic Force.
156	0·5569	0·4376
136·5	0·7374	0·5765
116·5	0·9455	0·7280
96·5	1·1862	0·8897
76·5	1·4311	1·0559
56·5	1·6518	1·1929

Hence it appears that the bar heated to 80° had not only lost much of its magnetic virtue, but that this loss was not uniform along the whole length of the bar, being

greater towards the extremities a' b' than towards the middle. This may be easily seen by dividing the forces in columns 2 and 3 by one another, when it will appear that the quotients are greater for points nearest a' and b'.

M. Kupffer next studied the changes which take place in the forces of a magnetic needle when its temperature is increasing, the heat being kept constant during the time of each experiment. He used a cylindrical needle of fused steel, 0·57 millimetre long, and 2·365 grammes in weight. The temperature increased from 8½° to 18°, and the deviation of 300 oscillations varied from 777½ to 781, which shews, as Coulomb had previously observed, that the magnetic force diminished as the temperature increased. By another series of experiments, M. Kupffer has shewn, that the diurnal variations of the needle did not at all affect these results.

In order to determine the law of the decrease of the magnetic forces at temperatures above 30°, he made a needle oscillate above a newly magnetized bar 0·5 millimetre long, the opposite poles looking to each other, and he raised the temperature of the bar from 13° to 80°, by means of hot water. At 13°, the needle, when by itself, performed 300 oscillations in 762″, and in presence of the magnet it lost only 429″. When brought to the temperatures in the table, and then cooled, the oscillations of the needle were observed.

Temperature of the Magnet.	Duration of 300 Oscillations.
13°	429
80	476
21	464½
13	463
11	462½

Hence it appears that the magnetic force diminishes with heat, and that a magnet at the temperature of 13°, when heated to 80°, and then cooled to 13°, does not

resume its first magnetic state, which is diminished. The cause of this is, that in cooling slowly the bar loses a part of its temper, and consequently a part of its free magnetism.

From these observations M. Kupffer deduces the following formulæ, which represent with great accuracy the influence of temperature, viz.

$$x = \frac{n}{\sqrt{c + \mathrm{F}}}$$

$$x' = \frac{n}{\sqrt{\left(c + \mathrm{F} - \frac{(1-q)^{\mathrm{F}}}{67}\right)(t-13)}},$$

where c is the force exerted by the earth on the oscillating needle.

x, the number of seconds in which n oscillations are made.

F, the force exerted by the bar at the same temperature.

x', the number of seconds which the same needle employs at the temperature t.

p, the intensity of the magnetic force of the bar at 13°; and

q, the intensity of the same force at 80°.

M. Kupffer proceeded to examine the effects which the heating of only one pole of a magnet produced upon the distribution of its magnetism. With this view he placed a magnet parallel to a needle suspended horizontally, the dissimilar poles being placed opposite to each other. The needle will not remain in the magnetic meridian unless its neutral point and that of the bar are in the same line perpendicular to the needle. This position may be found by a few trials. When by shifting the magnet its neutral point approaches one of the poles of the needle, and always in the same direction, this pole will be repelled, because the opposite pole of the needle is more strongly attracted

by the corresponding pole of the magnet, which is brought near it, while the other is removed from it.

Let us now heat the north pole of the magnet; the south pole of the needle opposite to it will be soon attracted. Hence it is clear that the point of indifference, or neutral point, has receded from the heated pole, or from the pole whose magnetic intensity is diminished, which agrees with the law of Coulomb. The following results were obtained with a magnet 0·5 millimetre long, the needle being placed in the magnetic meridian: —

Temperature at the extremity of the Bar.	Duration of 10 Oscillations.
0° Reaumur.	275·5 seconds.
13	276
40	278
56	279·5
15	277·5
11	277

" When the magnet had cooled slowly, the needle returned gradually to its first position; but it never recovered it entirely. By the earth's action only, the needle performed 50 oscillations in 207″.

When a bar of soft iron was substituted for the magnet, and placed in the magnetic meridian, it was magnetized by the action of the earth. When one of its extremities was heated, the pole of the needle next it was *attracted* instead of *repelled*, the neutral point having *approached* to the heated extremity, in place of *receding* from it as formerly. Hence the magnetic force of the iron was *increased* by heat.

In examining the diurnal deviations of the needle when under the influence of magnets, Mr Christie conceived that the deviations might be partly the effect of changes in the temperature of the magnets; and he therefore undertook a series of experiments to determine the precise

effects of changes of temperature on magnets. By a peculiar apparatus, and a method of observation which our limits will not allow us to introduce, he obtained the following results : —

Mean Temperature of the Magnets. Fahr.	Difference of Heats in successive Observations.	Magnetic Intensity.	Variation of Intensity for 1° of Fahr.
62°·05	— 3°·00	212·5620	0°·1268
59 ·05	+ 18 ·60	212·9423	0 ·1247
77 ·65	— 3 ·65	210·6228	0 ·1004
74 ·00	— 3 ·35	210·9892	0 ·1279
70 ·65	— 3 ·50	211·4178	0 ·1193
67 ·15	— 3 ·35	211·8353	0 ·1138
63 ·80	— 1 ·75	212·2167	
62 ·05		212·4640	0 ·1413

By discussing these results, Mr Christie concludes that 0·1226 is the mean variation of the intensity of the magnets, from a change in their temperature of 1° between the temperatures of 59°·05 and 77°·65. Taking the case where the intensity at 60° was 218, the change for 1° was 0·123; and supposing the intensity to be 1, each degree will produce a diminution of 0·000564.

From a number of experiments made with a balance of torsion, the needle being suspended by a brass wire $\frac{1}{450}$th of an inch in diameter, Mr Christie ascertained the following facts :

1. Beginning with — 3° of Fahrenheit, up to 127°, the intensity of magnets decreased as their temperature increased.

2. With a certain increment of temperature the decrement of intensity is not constant at all temperatures, but increases as the temperature increases.

3. From a temperature of about 80°, the intensity decreases very rapidly as the temperature increases ; so that

if, up to this temperature, the differences of the decrements are nearly constant, the differences in the decrements also increase.

4. Beyond the temperature of 100° a portion of the power of the magnet is permanently destroyed.

5. On a change of temperature, the most considerable portion of the effect on the intensity of the magnet is produced instantaneously, shewing that the magnetic power resides on or very near the surface.

6. The effects produced on soft iron by changes of temperature are directly the reverse of those produced on a magnet; an increase of temperature causing an increase in the magnetic power of the iron. This was observed between the temperatures 50° and 100° Fahr. Mr Christie regards this fact as a strong argument against the hypothesis, that the action of iron upon the needle arises from the polarity which it receives from the earth. *

* See *Philosophical Transactions*, 1825, p. 1—65.

CHAPTER VI.

ON THE ACTION OF SIMPLE IRON BODIES ON THE MAGNETIC NEEDLE.

Mr Barlow undertook the interesting experiments which we are about to describe, with the view of discovering some method of correcting the local attraction of a ship's guns and other iron on the compass-needle.

His attention was first directed to the action of solid spheres and spherical shells of iron; but he afterwards applied the principles to which he was led, to the action of bars and plates of simple iron, and to irregular masses. We shall therefore lay before our readers, in three separate sections, the results of his experiments and theoretical investigations respecting these two forms of unmagnetized iron.

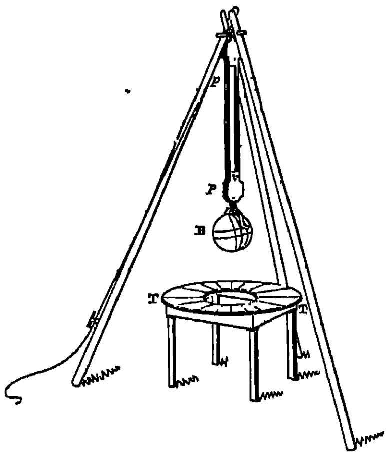
Sect. I.—*On the Action of Spheres and Spherical Shells of Iron on the Magnetic Needle.*

The earliest experiments of Mr Barlow, by which he was led to some of the properties of iron spheres, were made in an imperfect manner; but the phenomena were such as to induce him to construct an apparatus capable of affording him the most accurate measures of the deviation of the needle.

The apparatus which he finally employed is shewn in fig. 36. It consists of a large and steady round table TT, having its surface horizontal. The points of the compass are laid down on its upper face. In its centre is a hole

18¼ inches wide, for receiving an eighteen-inch or smaller iron shell or ball B, which is suspended above it by pulleys *p p*, which allow the observer to raise or lower it at pleasure. When a diameter of this table is brought into the magnetic meridian, Mr Barlow found, that in whatever part of the table a compass-needle was placed, except in the meridian, the *south* end of the needle was drawn

Fig. 36.



to the ball when the latter was wholly above the table, as in the figure. The attraction increases as the ball descends, till at a certain point it is a maximum, and then decreases again towards zero as the ball descends farther. Hence it is clear, that there is all round the ball a position where the attraction is zero; and it was easily observed that these points lay in a plane inclined to the horizon. In this way Mr Barlow established his fundamental principle, that

In every ball or shell of plain unmagnetized iron there exists a plane of no attraction, or a plane in which the iron produces no disturbance on the needle, and which plane inclines from north to south (magnetic,) forming with the horizon an angle equal to the complement of the dip.

This line on the surface of the ball may be called the magnetic equator; and, taking the meridian which passes through the east and west points as the first, Mr Barlow

is able to designate every part of his iron sphere by the magnetic longitude and latitude of that point.

Mr Barlow therefore proceeded to determine whether the quantity and deviation at any point could be expressed by any function of the latitude and longitude of that point, when the mass of the ball and the distance of the needle from it were constant. From these experiments, which it is unnecessary to detail, he found,

That the tangent of the deviation of the needle is proportional to the rectangle of the sine and cosine of the latitude, or to the sine of the double latitude.

By observing the deviations throughout a great circle in which the longitude was constant, and also in a circle in which the latitude and longitude were variable, he found the following law,—

That the tangent of the deviation of the needle is nearly proportional to the sine of the double latitude multiplied by the cosine of the longitude.

By comparing the constant numbers obtained on the preceding principles at different distances *from the centre of the sphere,* Mr Barlow found,—

That the tangent of the deviation is inversely proportional to the cube of the distance.

The remaining object of Mr Barlow's inquiry was a very interesting one, namely, to determine the law of the deviation as dependent on the mass of the iron ball by the action of which it was produced. The result was equally new and unexpected. He found,—

That the tangent of the deviation was directly proportional to the cube of the diameter of the ball or shell; but that it is still wholly independent of the mass, being the same in quantity whatever be the thickness of the metal, provided only that it exceed one-twentieth of an inch.

Hence it follows, *that the entire magnetic power of an iron sphere resides on the surface, and is independent of the solidity.*

Mr Barlow was so much surprised at this result, that he constructed a ten-inch shell of tin plate, and another of iron plate, the former weighing forty-three ounces and the latter forty-five ounces, and he found that the power of neither was so great as that of the solid ball of the same diameter, but approached to it in the ratio of two to three. As the thickness of the iron in these shells was at an average about one-thirtieth of an inch, Mr Barlow concluded that the magnetic fluid requires a certain thickness of metal, exceeding one-thirtieth of an inch, in order effectually to develop itself, and act with its maximum energy.

This important result was some time afterwards verified by Captain Kater, with three cylinders, one of soft iron, and one-tenth of an inch thick; another of what is called chest-plate, 0·185 of an inch thick; and the third solid. The deviations produced by these three cylinders, when reduced to the same extent of surface, were 141, 184, and 187, thus proving that the cylinder whose thickness was only 0·185, or between one-fifth and one-sixth of an inch thick, had the same magnetic power as a solid cylinder of iron. The distribution of magnetism on the surface of magnetic bodies presents us with another interesting analogy between the magnetic and electric fluids; and it deserves our particular notice, that, in the results obtained by Mr Barlow, the action of the sphere is related to the centre of its mass, and not to the poles of its magnetic equator.

Mr Barlow next proceeds to the investigation of analytical formulæ which shall exhibit the action of iron spheres upon a magnetic needle. In this inquiry he sets out with the established experimental fact already mentioned, *that the entire magnetic power of an iron sphere resides on the surface, and is independent of the solidity;* and he proceeds on the following hypothesis:—

1. Magnetic phenomena are due to the existence of two fluids in a greater or less degree of combination, and such that the particles of the same fluid repel, and those of an opposite nature attract, each other.

2. These fluids in iron bodies exist naturally in a state of combination and equilibrium till that state is disturbed by some exciting cause.

3. But if a body already magnetic—*i. e.* one in which the fluids are held in a state of separation—be brought within the vicinity of a mass of iron, such as is supposed above, the concentrated action of each fluid in the magnetized body will act upon the latent fluids in the quiescent body, by repelling those of the same, and attracting those of the contrary kind, and thus impress upon the latter a temporary state of magnetic action, which will remain only while the two bodies maintain their respective situations.

4. The quantity of action impressed upon the iron body will depend, 1*st*, upon the intensity of the exciting magnet; 2*dly*, upon the capacity of the quiescent body for magnetism, or the quantity of those fluids contained in it; and, 3*dly*, upon the cohesive power of the iron; which latter quality determines the depth to which the exciting magnet is able to disengage the two fluids.

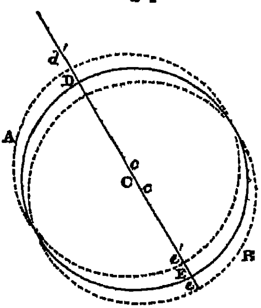
The above embraces every case, namely, of any magnet, natural or artificial, developing the magnetism in any given iron body; but the displacement occasioned by the magnetic action of the earth, or spheres of iron, is more limited in its results, and more susceptible of correct mathematical investigation.

5. In this case, for instance, we may suppose the action to take place on every particle of the mass in lines parallel to each other, and corresponding in direction with the dipping needle; also, that every particle is at the same distance from the centre of the disturbing force, and

consequently, that the displacement in each particle is equal also.

6. For the sake of illustration, let ABED represent a sphere of iron in its non-magnetic or quiescent state, and let CM be the line on which the terrestrial magnetism is exerted from a centre of action M, which is at such a distance that the diameter of the sphere is inconsiderable in comparison with it; then every particle on its surface, and to a certain distance within it, will be acted

Fig. 37.



upon by equal powers, and in directions parallel to each other, whereby the fluids in the quiescent body, before in a state of combination, will be separated in each particle; and the two fluids may now therefore be conceived to form two spherical shells A e B d, A e' B d', whose centres of action will be $c\,c$, their distances from each other being greater or less, according to the circumstances stated in No. 4.

7. Therefore, in computing the action of such a mass of iron, in its temporary state of magnetism, upon a distant particle of magnetic fluid, Mr Barlow refers it to these centres, and assumes that the law of action in this, as in other cases of emanating forces, is inversely as the squares of the distance.

By means of this hypothesis, Mr Barlow arrives at the following formula for the deviation Δ of a horizontal needle.

$$\text{Tan. } 7\,\Delta = \frac{C}{M} \cdot \frac{3 r^3}{2\, d^3 \cos.\, \delta} \,(2\,\lambda \cdot \cos.\, l)$$

where r = radius of the iron spheres;

d = the distance of the needle from the centre of the spheres;
λ = the complement of the magnetic latitude;
l = the complement of the magnetic longitude;
δ = the dip of the needle; and
$\frac{C}{M}$ = 1·0589, a constant quantity for cast-iron balls and shells, of every diameter, and for all distances and positions.

From this formula it necessarily follows,—

1. That though the development of the magnetism of the spheres takes place by the hypothesis only at the surface, yet the effect, as shewn by the tangent of the deviation, is proportional to the cube of the diameter.

2. That the tangent of deviation is inversely as the cube of the distance.

3. That the tangent of the deviation is proportional to the sine of the double latitude and cosine of the longitude, the latter being extended from the east and west points.

These are the very laws which Mr Barlow had deduced from experiment, and he has established the correctness of his formula by comparing it with a great body of experiments made by himself and Mr Christie, and also with observations on the dipping needle.

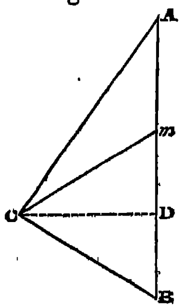
SECT. II.—*On the Action of Simple Iron Bars and Plates on the Magnetic Needle.*

As spherical bodies possess the peculiar property of having their centre of attraction in the centre of the mass, the former becomes a fixed point, whatever be the distance of the magnetic needle. As this is not the case, however, with bodies of other forms, such as bars and

plates, Mr Barlow was desirous of ascertaining whether, in these cases also, the magnetic attraction of the body could be referred to the action of two centres indefinitely near to each other in the general centre of attraction of the surface of the body, namely, that point into which, if all the matter of the surface were collected, its action on the centre of the needle would be the same as the action of the whole body in its natural form.

In pursuance of this plan, he supposes A B to be a bar of iron, and C the place of the needle, and, letting C D fall perpendicular on A B, he joins A C, m C, B C. He then finds the following expressions for the deviation, $\tan. \Delta = A \frac{m n \cos. l}{(m^2 + n^2)^{\frac{1}{4}}}$, A being a constant quantity, l the longitude, m the force in the direction D C, and n the force in D A. In the experiments with which Mr Barlow proposed to compare this formula, the needle was placed due east and west of the bar, the longitude of its position was zero, and hence $\cos. l = 1$. The formula, therefore, becomes

Fig. 38.



$$\tan. \Delta = A \frac{m n}{(m^2 + n^2)^{\frac{1}{4}}} \text{ or } \tan. \Delta \frac{(m^2 + n^2)^{\frac{1}{4}}}{m n} = A,$$ whatever may be the distance of the needle or its position, provided its longitude be zero. The following experiments were made by Mr Charles Bonnycastle, with a bar twenty-four inches long and an inch and a quarter square, inclined in the direction of the dipping needle. The magnetic needle was placed to the east and west of the bar, first opposite to its centre m, and then at every three inches from the centre to the extremities, at the distance of twelve and sixteen inches from the axis of the bar. The following were the results:—

Distance of Compass from Bar in inches.	Distance below Centre.	Observed Deviation.	Value of $\frac{mn}{(m^2+n^2)^{\frac{3}{2}}}$	Values of A.
16	3	2° 20′	·00240	17·03
16	6	4 25	·00438	17·62
16	9	5 45	·00563	17·88
16	12	6 0	·00596	17·63
12	3	5 20	·00484	19·28
12	6	10 0	·00899	19·62
12	9	12 0	·01152	18·45
12	12	11 30	·01160	17·54
				Mean....18·13

These results Mr Barlow justly regards as a farther proof of the accuracy of the principles upon which his hypothesis is founded, and of his general deduction that the action of plain unmagnetized iron on a compass needle may be referred to two poles indefinitely near to each other in the common centre of attraction of the surface of the body.

Mr Bonnycastle performed another series of experiments with a plate of malleable iron twelve inches square and half an inch thick, and he obtained results almost equally accordant with Mr Barlow's hypothesis.

SECT. III.—*On the Action of Irregular Masses of Iron on the Magnetic Needle.*

Mr Barlow was next desirous of ascertaining if the same law which applied to spheres, bars, and plates, was true in irregular masses of ron, such as a 24-pounder gun,—an experiment peculiarly applicable to the object he had in view. He found that the plane of no attraction existed in the most irregular masses of iron, and the agreement between the observed deviations produced by the gun,

and those calculated by his formula, was such as to satisfy him that the same laws applied to irregular as to regular masses of iron; and he was thus furnished with the means of computing the local attraction of a ship's guns upon the compass under all circumstances, and in all parts of the world.

These views have been strikingly confirmed by several ingenious observations, made, without knowing of Mr Barlow's labours, by Mr Lecount of the navy, with bars, handspikes, mast rings, and various other iron bodies; from which he concluded "that a plane or circle held east and west (magnetic) and at right angles to the direction of the dipping needle, divides the north from the south magnetic effluvia, each lying on that side to which the dipping needle points; and by referring the position of all iron bodies to this plane, the plane of section shall divide the two into north and south polarity, provided it be of uniform thickness, or, if not, the section must be drawn through its centre of (gravity) attraction."*

* Lecount *on the Magnetic Properties of Iron Bodies.*

CHAPTER VII.

ON THE INFLUENCE OF MAGNETISM ON CHEMICAL ACTION.

An opinion had long prevailed among philosophers that the phenomena of magnetism and electricity had a similar origin; and hence various observers had been led, previous to the discovery of electro-magnetism by Oersted, to inquire if any actions of a chemical nature could be produced by magnetism.

The German philosopher Ritter was the earliest and the most active of these inquirers. He maintained that a magnetic wire, combined with another wire not magnetized, produced contractions in a frog, the south pole of the wire-magnet producing stronger contractions than the unmagnetized wire; and as he had constantly observed that the metals most susceptible of excitation excited the strongest contractions, he concluded that the south pole of a magnet has a greater affinity for oxygen than simple iron, and the north pole a less affinity. Hence he was led to confirm these views by means of several chemical re-agents. He placed a magnetized wire upon pieces of glass in an earthenware dish containing weak nitric acid, when he found that the south pole was more corroded by the acid than the other, and was soon encircled with a deposition of oxygen greater than that at the other pole. In another experiment he took two flasks filled with tincture of turnsol, in one of which he placed the two south poles of two wire-magnets, and in the other the north poles of two similar magnets. In the last flask the oxidation of the wires was much greater than in the first.

The difference in the oxidation of the south pole was exhibited by Ritter in another way. He took three small

and equal bottles filled either with pure or slightly acidulated water, and having placed in one the south pole of a wire-magnet, in another the north pole, and in the third the extremity of an unmagnetized wire of the same length, he observed that the south pole first began to deposite oxide, the unmagnetized wire next, and the north pole last. In order to exclude the access of air, the surface of the water should be covered with very fresh oil of almonds; and as light accelerates oxidation, none of the bottles should be more exposed to the sun than the rest. In support of this last observation, Ritter exposed two iron wires to the sun when placed in water, and having covered one of the bottles with black paper, he found that the wire in the uncovered bottle was oxidated more rapidly than the other.

Ritter repeated the preceding experiment with the three bottles containing an infusion of litmus in place of acidulated water. The south pole reddened the infusion most, the unmagnetic wire less, and the north pole least of all. A week is required to produce a distinct effect; and in order even to effect this, Ritter found it necessary to add as much acetic acid as would incline the infusion to red without completely changing its colour.

The following experiment of Ritter, if correctly repeated, establishes the same result. We shall give it nearly in his own words: "Sixteen magnetic wires, of equal size and power, were placed in six vessels, all equally full of a mixture of one part nitric acid and thirty-six parts water, in the following manner: In the first glass were placed two wires, one with the north pole immersed in the fluid, the other with the south, and not more than half a line asunder; in the second, the same, but the wires an inch and three-fourths apart; in the third and fourth were each three wires, with the south poles of all immersed, but their distances in the two glasses different, as in the first and second; in the fifth and sixth were wires similarly

arranged, but with the north poles immersed. Different quantities of oxide were gradually deposited, and, to express the whole in a few words, we will call the south pole S, the north pole N, their greater distance g, and their less p, and we will express the order of oxidations as follows: $SNg > SNp > 3Sp > 3Sg > 3Np > 3Ng$. On the nineteenth day it was observed that the loss of fluid by evaporation had not been equal in all the vessels, but took place in the inverse order of the oxidations. All the magnetic wires were weakened in power; NSg least, NSp more; of the wires $3Sp$, two had lost less power than the third; and in like manner $3Sg$, $3Np$, $3Ng$, had each two left more powerful than the third; the strongest were equal to NSg."

The next experiments on this subject were made by M. Muschman, professor of chemistry in the university of Christiania, who endeavoured to ascertain the effect of the earth's magnetism on the precipitation of silver. In his chemical course in 1817, when he was desirous of explaining the chemical theory of the tree of Diana, he took a tube like a syphon, and poured mercury into it, which accordingly occupied the lower part of the two branches: above the mercury he poured a strong solution of nitrate of silver. He then placed the two branches of the syphon so that the plane passing through them was in the magnetic meridian, and after standing a few seconds, the silver began to precipitate itself with its natural lustre; but it accumulated itself particularly in the northern branch of the syphon, while that which was less copiously precipitated in the other branch had a less brilliant lustre, and was mixed with the mercurial salt deposited from the solution. M. Muschman and Professor Hansteen repeated this experiment in an improved form with the very same result. On this occasion they used simultaneously two syphons prepared in the same manner, the one being

placed in the direction of *north* and *south*, and the other in that of *east* and *west*. The silver began to precipitate itself in the direction of *north* and *south*, and it particularly raised itself in the *north* branch with a lustre more brilliant than in the *south* one; whereas in the syphon whose plane lay *east* and *west*, *no change had taken place even at the end of twelve hours*. Hence the two Norwegian philosophers concluded, with some reason, that the magnetism of the earth had an influence on the precipitation of silver from a solution of its nitrate; and M. Muschman inferred, from the experiment, the identity of galvanism and magnetism. He regarded every dissolution as the result of a galvanic effect, the precipitated metal carrying off the electricity set at liberty, and carrying itself, in order to be disengaged, to the place where it could find the opposite electricity, which was the north pole. M. Muschman considered this hypothesis confirmed by the geological fact, that at Königsberg silver was found in the metallic form, stretching from north to south; and the presence of silver is always indicated by a certain quantity of pyrites and blendes. Hence he conceived that the silver had been insensibly united to sulphur, and that by the effect of the earth's magnetism alone it had been carried towards the copper and the zinc.

M. Fresnel made a series of experiments with the view of decomposing water by the magnet. He proposed to produce an electric current in an electro-magnetic helix enclosing a bar-magnet covered with silk. The two ends of the wire were plunged in slightly acidulated water, and he observed very decided effects; but there were so many anomalies in the result, which he could not explain, that he abandoned the inquiry. He was particularly struck with the fact that the wire which should be the positive one was strongly oxidated, whilst the other extremity preserved its metallic lustre during a whole week. The

negative extremity was covered with a saline deposite, which he conjectured to be sulphate of lime, and which he supposed had protected the wire from oxidation.

M. Erdman, after a very elaborate inquiry into the effects of magnets as chemical agents, came to the conclusion that the observed phenomena were due to the influence of other causes, which had not been sufficiently guarded against.

A curious fact, connected perhaps with the class of phenomena under our observation, was noticed by M. Lebaillif. He observed that the poles of a magnetic needle delicately suspended were repelled by pieces of antimony or bismuth that were brought near them.

CPAPTER VIII.

ON THE LAWS OF THE MAGNETIC FORCES, THE MUTUAL ACTION OF MAGNETS, AND MAGNETIC CURVES.

SECT. I.—*On the Law of the Magnetic Force.*

IN our history of magnetism we have given very full details of the various attempts which were made by philosophers to determine the law according to which the intensity of the attractive and repulsive power of magnets varied with the distance at which these forces were exerted. Like all other laws, an approach to the discovery of it had been made by various philosophers; but the merit of its perfect establishment undoubtedly belongs to Dr Robison and Coulomb, the last of whom placed it beyond the reach of doubt. The difficulties which were to be overcome in this inquiry arose from the invariable co-existence of two opposite polarities in each of the two bodies whose mutual action was under examination; and this difficulty was increased from these polarities not being concentrated in particular points, but diffused in an unequal degree over each half of the magnet and the needle.

In this delicate inquiry Coulomb employed two methods. In the first he suspended a magnetic needle by a silk fibre, and when it was in the magnetic meridian, he presented to it at different distances another magnetic needle, and determined by observation and calculation the force with which they acted upon each other at these distances. A needle an inch long, weighing seventy grains, and magnetized to saturation, was suspended by a fibre of silk three lines long, and a steel wire magnet

twenty-five inches long was placed vertically in the magnetic meridian at different distances, so that its south pole was always ten lines below the northern extremity of the suspended needle. The needle was now made to oscillate when the magnet was at different distances from it, and the following were the number of oscillations in 60″, the number being fifteen when the magnet was removed, and the needle influenced only by the magnetism of the earth.

Distance of a Wire Magnet from the middle of the Needle.	Number of Oscillations in 60″.
4 inches	41
8 ditto	24
16 ditto	17

By means of the formula for the pendulum, in which the forces are in the direct ratio of the square of the number of oscillations performed in the same time, Coulomb has computed their intensity. As all the forces concerned are in the plane of the magnetic meridian, the force which produces the horizontal oscillations depends on the parts of these forces which are decomposed in a horizontal direction. Now, Coulomb had demonstrated that the magnetic fluid might be considered as concentrated at a point ten lines from the extremity of the wire-magnet; but as the suspended needle was one inch long, its north pole was attracted at the distance of three and a half inches, and its south pole at the distance of four and a half inches, so that four inches was the mean distance at which, in the first experiment, the lower pole of the wire-magnet exerted its action on the two poles of the needle. In the second experiment the mean distance was eight inches. But as the horizontal force which produces the oscillations is the square of the number performed in 60″, the magnetic force of the earth will be 15^2, and the combined forces of the earth and the wire-magnet will, in the first, second, and third experiments, be 41^2, 24^2, and 17^2,

so that the forces which emanate from the wire-magnet will be 41^2-15^2, 24^2-15^2, 17^2-15^2, whence we deduce the following results:

	Mean Distance.	Force depending on the Action of the Wire-magnet.
1*st* experiment	4 inches.........	$41^2-15^2 = 1456$
2*d* experiment	8 ditto	$24^2-15^2 = 351$
3*d* experiment	16 ditto..........	$17^2-15^2 = 64$

The distances in the first and second experiments being as one to two, the variation of the force would have been exactly as the squares of these numbers had the force in the second experiment been 364 instead of 351; and the same would have been the case had the force in the second and third experiments been 332 and 83, instead of 351 and 64. This difference, therefore, requires to be investigated. Coulomb has accounted for it, and calculated the correction for these numbers in the following manner. In the experiments the action of the superior pole of the wire-magnet was neglected. The distance of its inferior pole from the centre of the needle was sixteen inches, and the distance of the superior pole from the centre of the needle is nearly $\sqrt{(16^2+23^2)}$, so that the force of the former is to that of the latter nearly as 100 to 19. Hence, as the oscillations of the needle are produced by the action of these two poles, which exert their force in opposite directions, the square of the number of oscillations which the single action of the inferior pole of the magnet would produce should be diminished $\frac{19}{100}$ths by the opposite action of the superior pole; so that 64 is only the excess of the real amount of the single action of the lower part of the magnet over $\frac{19}{100}$ths of the number which represents it. The true value will therefore be 79. The true intensities of the forces will, at the distances 4, 8, and 16 inches, be 1456, 351, and 79, or nearly in the inverse ratio of the squares of the distances.

M. Coulomb has in like manner demonstrated, that the repulsive force of similar poles follows the same law of the distance.

The *second* method employed by Coulomb requires the use of the magnetic balance, which is represented in figs. 39 and 40, which is a modification of the torsion balance already described in our article on ELECTRICITY. The suspending wire, *a b* fig. 39, carries at its lower extremity a pair of pincers *c*, which holds a stirrup 1, 2, 3, formed of a plate of very light copper. In this stirrup is placed a small piece of card covered with a coat of Spanish wax, on which is impressed the mark of the wire or bar of steel SN to be used, in order that it may always be put in the same position. Under the middle of the stirrup is fixed a vertical plane PP, wholly immersed in a vessel VV of water, the resistance of which may quickly stop the oscillations of the needle or magnet SN in the stirrup.

Fig. 39.

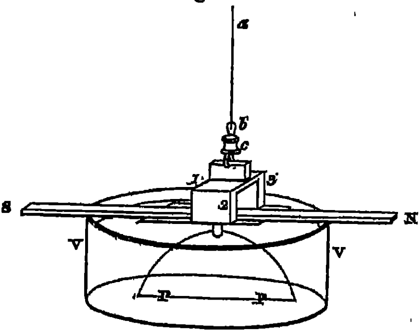
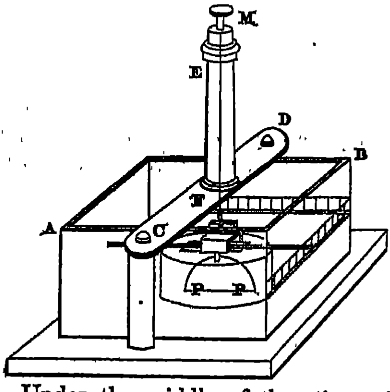


Fig. 40.



When fitted up for the experiments under our consideration, the apparatus shewn in fig. 39 is placed in a square box AB, fig. 40, three feet wide and eighteen inches high. At the height of nine inches above the bottom is placed a horizontal circle of wood or copper, two feet ten inches in diameter, and divided into degrees. On this box is placed a cross piece CD, which supports at its middle point a tube EF, thirty inches long, and terminating in a torsion micrometer at M. The pincer of this micrometer holds the upper end of a brass wire, to the other extremity of which is adapted a ring of copper intended to carry a steel needle.

Before the commencement of the experiment, the box AB is placed so that the direction of the magnetic meridian passes through the division *zero* and 18° of the horizontal circle. The next step is to place in the stirrup a well-magnetized steel needle NS, of a rectangular form, and to adjust the torsion micrometer M, so that the torsion of the wire is nothing when the needle MS is in the magnetic meridian, or that the magnetic meridian passes through the *zero* on the scale of the torsion micrometer. In the direction of the magnetic meridian, a vertical ruler of wood or copper, one or two lines thick, is fixed, so that the end of the needle may come against it when it is in the magnetic meridian.

Coulomb now took two wire-magnets, twenty-four inches long and one and a half inch in diameter, and he placed one of them in the stirrup, as at NS, and he determined the force with which the magnetism of the earth drew it back into the magnetic meridian. For this purpose he twisted the suspending wires *ab* through two circles or circumferences minus 20°, till the needle stopped 20°, from the magnetic meridian, so that, considering the forces as nearly proportional to the arcs (when the angle is about 20°,) about 35° of torsion were necessary to keep the magnetic needle one degree out of the magnetic

meridian. The two circles of torsion *minus* 20° are equal to $2 \times 360° - 20 = 700°$, the degrees of torsion required to keep the needle 20° out of the magnetic meridian; or 700° of torsion, are a measure of the directive force of the needle when 20° out of the magnetic meridian. For any other number of degrees, δ, the degree of torsion necessary to balance the directive force will be $700 \frac{\sin. \delta}{\sin. 2°}$, because the directive forces are proportional to the sines of the angles. But at 20° the angles may be substituted for the forces, and we shall have $\frac{700\ \delta}{20} = 35\delta$, that is, as we stated above, 35° of torsion will balance the directive force of the needle when one degree out of the magnetic meridian. Coulomb now placed the other similarly magnetized wire vertically in the magnetic meridian, so that if the two wires had been prolonged, they would have met at the distance of *ten* lines from their extremities, the point where the magnetism of each acts as if it were concentrated there. He placed the similar poles of each opposite to each other, and consequently the horizontal needle or wire was repelled out of the magnetic meridian; and it took a position at which the force of repulsion of the vertical needle or wire was balanced by the united forces of torsion and the earth's magnetism, which tended to bring the horizontal wire to rest. The following results were obtained after different trials:

Circles of Torsion given to the Suspending Wire by the Torsion Micrometer.	Observed Angles of Repulsion.
0	24
3	17
8	12

Now, in the first experiment, the angle through which the horizontal wire was repelled was 24°, reckoning from the zero of torsion; and when it rested in this position, it was

driven towards the zero by a force of torsion of 24° *plus* the directive force of the earth's magnetism, which being 35° for every 1°, amounts to $24^\circ \times 35^\circ = 840^\circ$. The total repulsive force was therefore $848^\circ + 24^\circ = 864^\circ$.

In the second experiment the torsion micrometer was turned round *three* circles in a direction opposite to the 24° first produced; but notwithstanding this great torsion, the horizontal wire-magnet, repelled by the vertical one, returned only to 17° from the magnetic meridian. The force of torsion was therefore 3 circles $+ 17^\circ = 1097^\circ$; but the directive force for 17° is $17^\circ \times 35^\circ = 595^\circ$, hence we have for the total repulsive force $1097^\circ + 595^\circ = 1692^\circ$.

In the third experiment the torsion micrometer was turned round eight circles, and the wire-magnet stopped at 12° from the magnetic meridian. The force of torsion was therefore 8 circles $+ 12^\circ = 2892^\circ$; but the directive force for 12° is $12^\circ \times 35^\circ = 420^\circ$, hence we have for the total repulsive force $2892^\circ + 420^\circ = 3312^\circ$.

As the arcs of repulsion are in these experiments so small, we may safely reckon them equal to their chords, and we obtain the following results:

Distances at which the Repulsive Force is exerted.	Corresponding Repulsive Forces in Degrees of Torsion.
12	3312°
17	1692
24	864

Assuming 3312° as correct, the other numbers ought to have been 1650 and 828 instead of 1692 and 864, if the force varies inversely as the square of the distance. The differences 42° and 36° correspond nearly with a degree of error in the observed position of the moveable steel wire, since the directive force is 35° for every degree of deviation from the magnetic meridian. Such an error is certainly a very small one in experiments of this kind,

and we therefore conclude that the attractive and repulsive forces of magnets decrease as the squares of their distances increase.

Had the experiments been made upon magnetic points, such an error would not have existed; but they were made with forces diffused over portions of the wire-magnet of some extent. In the last experiment (M. Biot remarks) "when the two wires were nearest each other, the influence of the points lying near the intersection was more weakened by obliquity than in the other experiment; or, in other words, there were at equal obliquities more points which acted in the greater distances (24 and 17) than in the smaller one (12.) But as we did not take this augmentation into account, we ought to find that the repulsive force observed at the smaller distance, being reduced in the ratio of the square of the distance, gives for larger distances repulsive forces a little more feeble than those which were actually observed.

In the first method of observation, Coulomb was obliged to calculate the effect of the distant pole; but in the present method this was unnecessary, as the wire-magnets were two feet long, and the greatest arc of repulsion, viz. 24°, corresponded to a distance of five inches between the repelling poles. The other poles were therefore at least four times more distant than those whose repulsive action was calculated; their direct action was therefore sixteen times weaker, besides being greatly weakened by the extreme obliquity with which it acted. Had the wire-magnets been shorter, the action of all the poles might have been taken into consideration.

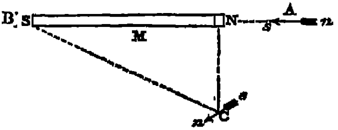
Sect. II. — *On the Mutual Action of Magnets.*

We have already seen, from Professor Barlow's experiments on spheres and bars of soft iron, that they act upon

needles, whether temporarily or permanently magnetized, as if their magnetism emanated from the centre of their surface, or from two points indefinitely near to each other. This, however, is not the case with permanent magnets, in which the magnetic force is concentrated in poles considerably distant from each other.

Case 1. When the needle or a small magnet is placed in the line joining the poles of the other magnet.—In considering the mutual action of magnets, we shall suppose the larger one N S to be fixed, and the smaller one *n s* to have the form of a needle, moveable in a horizontal plane round the pivot in its centre A, B, or C. Let the needle then be placed at A, with its centre A in the line S N prolonged, and let us suppose that the magnetic forces emanate from points N S; *n s* being the analogous poles of the needle.

Fig. 41.

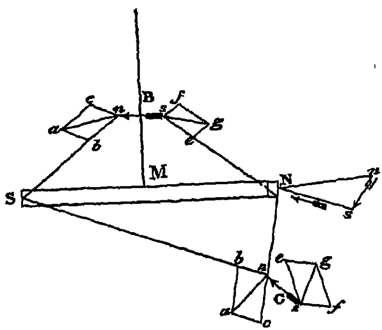


The north pole N of the magnet *attracts* the *south* pole *s* of the needle with a force inversely proportional to the square of N *s*, and *repels* the *north* pole *n* with a force inversely proportional to the square of N *n*. The effect of both of these forces is to bring *s* as near as possible to N, and to remove *n* as far as possible, that is, to place the needle in the same straight line as N S, as shewn in fig. 41.

Case 2. Let the needle *n s* be now placed at B, so that its centre B is anywhere in the direction of a right line, M B, perpendicular to the middle M of the magnet. When the centre of the needle is placed above M, it is quite clear that it will stand with its north pole *n* towards the south pole S of the magnet, and its south pole *s* towards the north pole N. When the needle is removed to B, the same thing will happen; S will attract *n* with a force equal to *n b*, while N repels *n* with a force *n a*, a

little less than $n b$, on account of the increase of distance. The result of these will be the force $n a$, in the diagonal of the parallelogram $n c a b$. In the same manner, the pole N will attract s with a force $e s$, and the pole S will repel s with a less force $f s$, the resultant of which is $s g$; but as the poles S N are equally strong, and act at equal distances upon the needle, the resulting force $a n$ must be equal to $g s$, and the needle will remain in that position which is parallel to the axis S N of the magnet.

Fig. 42.



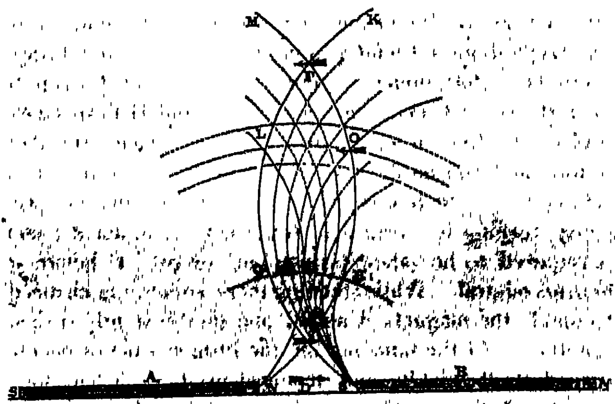
CASE 3. When the centre of the needle is placed in an intermediate position, as at C, fig. 42, neither in the axis NS, nor in the perpendicular MB, it will take an intermediate position, which may be thus found. Its north pole n is shewn in the figure as directed to the centre M of the magnet; but it cannot remain in this position; N repels n with a force equal to no, and S attracts it with a force nb smaller than nc, from the greater distance. The resultant of these is na, which is very different from ns. For the same reason, the south pole s, repelled by S with a force sf, and attracted by N with a force se, will have a tendency to move in the direction sg, nearly equal and opposite to each other; it will therefore take a position ns, fig. 42, nearly at right angles to its former position. It will rest therefore in its new position, with its north pole towards N, and its south pole towards S

If we project upon paper the magnet and the needle

placed in different positions, and make the forces of each pole of the magnet on each pole of the needle inversely proportional to the squares of the distances, it will be easy to find the position in which the needle will rest at any distance from the magnet, and at any position of its centre, with regard to the axis of the magnet.

When a needle is exposed to the combined action of two magnets, as shewn in the annexed figure, the phenomena, though capable of calculation by the principles already explained, are extremely perplexing and complicated when studied experimentally. Dr Robison, who first discovered and explained these phenomena, has given such an interesting account of them, that we shall make use of his description of the phenomena, leaving the explanation of them to the next section, on magnetic curves.

Fig. 43.



"Two large and strong magnets A and B were placed with their dissimilar poles fronting each other, and about three inches apart. A small needle, supported on a point, was placed between them at D, and it arranged itself in

the same manner as the great magnets. Happening to set it off to a good distance on the table, as at F, he was surprised to see it immediately turn round on its pivot, and arrange itself nearly in the opposite direction. Bringing it back to D, restored it to its former position. Carrying it gradually out along DF, perpendicular to NS, he observed it to become sensibly more feeble, vibrating more slowly; and when in a certain point E, it had no polarity whatever towards A and B, but retained any position that was given it. Carrying it farther out, it again acquired polarity to A and B, but in the opposite direction; for it now arranged itself in a position that was parallel to NS; but its north pole was next to N, and its south pole to S.

"This singular appearance naturally excited his attention. The line on which the magnets A and B were placed had been marked on the table, as also the line DF, perpendicular to the former. The point E was now marked as an important one. The experiments were interrupted by a friend coming in, to whom such things were no entertainment. Next day, wishing to repeat them to some friends, the magnets A and B were again laid on the line on which they had been placed the day before, and the needle was placed at E, expecting it to be neutral. But it was found to have a considerable verticity, turning its north pole towards the magnet B; and it required to be taken farther out towards F before it became neutral. While standing there, something chanced to joggle the magnets A and B, and they instantly rushed together. At the same instant, the little magnet or needle turned itself briskly, and arranged itself, as it had done the day before, at F, quivering very briskly, and thus shewing great verticity. This naturally surprised the beholders; and he now found, that by gradually withdrawing the magnets A and B from each other, the needle

became weaker, then became neutral, and then turned round on its pivot, and took the contrary position. It was very amusing to observe how the simply separating the magnets A and B, or bringing them together, made the needle assume such a variety of positions, and degrees of vivacity in each.

"The needle was now put in various situations in respect to the two great magnets; namely, off at a side, and not in the perpendicular DF. In these situations it took an inconceivable variety of positions, which could not be reduced to any rule; and in most of them it required only a motion of one of the great magnets for an inch or two, to make the needle turn briskly round on its pivot, and assume a position nearly opposite to what it had before."

In the preceding observations, the action of the one magnet tended only to change the direction of the other, and this change is clearly produced by the sum of the actions of the two poles of the magnet; for while the one pole tends to draw the one half of the needle into its position of equilibrium, the other pole repels the other half into the same position. The force, therefore, which thus acts upon a needle, is called the *directive force* of a magnet.

The *attractive force* of a magnet is, on the other hand, equal to the difference of the two forces exerted by its poles on the needle; and when the two forces happen to be equal, the attractive force will be nothing, and the needle will have no tendency to approach the magnet, though the directive power of the latter may be very great. This will be understood from fig. 42, when the needle *ns* is at right angles to the axis of the magnet. The attraction of the pole N for *s* is equal to its repulsion of *n*, and these two forces will neutralize each other, so as to prevent any tendency to approach N, even if the

needle *ns* were free to do it. On the other hand, in fig. 41, where the needle at C has its south pole *s* more attracted by N than its north pole *n* is repelled by it, the predominance of the attraction would carry the needle towards N if it were at liberty. These views explain the well-known fact, that a needle floated on a piece of cork quickly places itself in the magnetic meridian; but it never will approach the north side of the vessel. In order to explain this fact, Dr Gilbert asserted, that the directive power of a magnet extended much farther than its attractive power; a mistake which arose from his not having observed the effects of the simultaneous action of the four poles of the magnets which acted upon each other.

SECT. III.—*On Magnetic Curves.*

The name of magnetic curves has been given to those curves into which an infinite number of very minute needles would arrange themselves when placed round a magnet, and at liberty to move round an axis. A rude idea of these curves is given by the appearance of iron filings when scattered upon a sheet of paper, and agitated immediately above a magnet.

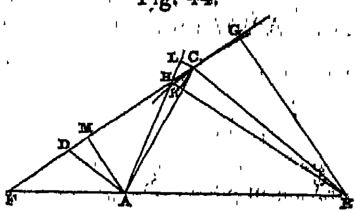
The action of a magnet upon a needle is greatly simplified when the needle is so small that its two poles may be considered as coincident; in which case the difference between the action of any one pole of a magnet upon them will be infinitely small. When this is the case, the directive force of the magnet upon the small needle must be very considerable, while the attractive force, measured by the difference of the action on the two poles, is nothing. Hence it is that alone which is concerned in the arrangement of minute needles or particles subjected to the action of a magnet.

An investigation of the force of the magnetic curves was made by Professor Playfair, at the request of Professor Robison. Professor Leslie afterwards undertook the same investigation;* and Dr Roget† has more recently given a more simple demonstration of the two fundamental propositions respecting them, and has described an instrument which he has invented for the mechanical description of these curves. Mr Playfair's investigation, which is sufficiently simple, is as follows; the only change which we have made upon it being the substitution of the second power of the distance for the mth power as used by him.

PROP. Two magnetical poles being given in position, the force of each of which is inversely as the square of the distance from it, it is required to find a curve, in any point of which a needle (indefinitely short) being placed, its direction, when at rest, may be a tangent to the curve.

"1. Let A and B be the poles of a magnet, C any point in the curve required; then we may suppose the one of these poles to act on the needle only by repulsion, and the other only by attraction, and the direction of the needle when at rest will be the diagonal of a parallelogram, the sides of which represent these forces. Therefore, having joined A C and B C, let A D be drawn parallel to B C, and make $\frac{1}{AC^2} : \frac{1}{BC^2} = AC : AD$; join C D, then C D F will touch the curve in C.

Fig. 44.



* *Geometrical Analysis.*

† *Journal of the Royal Institution of Great Britain*, vol. i. p. 311. Feb. 1831.

"2. Hence an expression for A F may be obtained; for, by the construction, $AD = \frac{AC^3}{BC^2}$; and since $BC : AD = BF : FA$, and $BC - AD : AD = AB : AF$, we have $AF = \frac{AB \times AC^3}{BC^3 - AC^3}$.

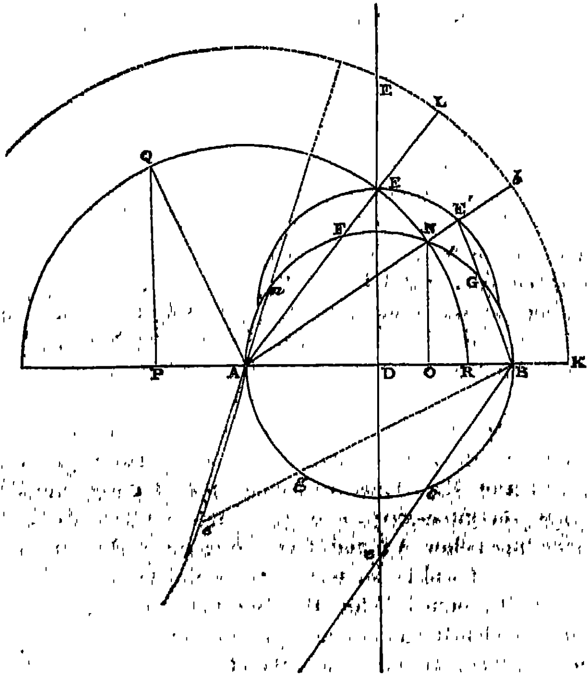
"3. A fluxionary expression for A F may also be found in terms of the angles C A B, A B C. In C F take the indefinitely small part C H; draw A H, B H, and from C draw C L perpendicular to A H, and C K to B H; draw also B G and A M at right angles to F H. Let the angles $CAB = \varphi$ and $CBA = \psi$, then $CAH = \dot{\varphi}$ and $CBH = -\dot{\psi}$; also $CL = AC \times \dot{\varphi}$, and $CK = -BC \times \dot{\psi}$. Now $HC : CL = AC : AM = \frac{AC^2 \times \dot{\varphi}}{HC}$; and for the same reason $BG = -\frac{BC^2 \times \dot{\psi}}{HC}$. Therefore, since $AF : FB = AM : BG$, we have $AF : FB = \frac{AC^2 \times \dot{\varphi}}{HC} : -\frac{BC^2 \times \dot{\psi}}{HC}$, and $AF : AB = \sin. \psi^2 \dot{\varphi} : -\sin. \psi^2 \dot{\varphi} - \sin. \varphi^2 \dot{\psi}$; wherefore, if $AB = a$, $AF = \frac{-a \dot{\varphi} \sin. \psi^2}{\dot{\psi} \sin. \varphi^2 + \dot{\varphi} \sin. \psi^2}$.

"4. If this value of A F be put equal to that already found, a fluxionary equation will be obtained, by the integration of which the curve may be constructed. Because $AF = \frac{AB \times AC^3}{BC^3 - AC^3}$; and since $AC = \frac{a \sin. \psi}{\sin. (\varphi + \psi)}$, and $BC = \frac{a \sin. \varphi}{\sin. (\varphi + \psi)}$, we have by substitution $AF = \frac{a \sin. \psi^3}{\sin. \varphi^3 - \sin. \psi^3} = -\frac{a \dot{\varphi} \sin. \psi^2}{\dot{\psi} \sin. \varphi^2 + \dot{\varphi} \sin. \psi^2}$. Hence, $\sin. \varphi^2 \times \dot{\psi} \sin. \psi^3 + \dot{\varphi} \sin. \psi^5 = -\sin. \psi^2 \times \dot{\varphi} \sin. \varphi^3$

$+ \varphi$ sin. ψ^2, and therefore $\dot{\psi} \quad \psi + \dot{\varphi}$ sin. $\varphi = 0$, and cos. $\varphi +$ cos. $\psi = C$."

"5. Hence, if, beside the points A and B, any other point be given in the curve, the whole may be described. For instance, let the point E be given in the curve, and in the line D E which bisects A B at right angles. Describe from the centre A a circle through E, viz. Q E R, then A D being the cosine of D A E to the radius A E

Fig. 45.



the sum of the cosines of $\varphi \times \psi$ will be everywhere (to the same radius) $= 2$ A D $=$ A B. Therefore, to find

E′, the point in which any other line A N, making a given angle with A B, meets the curve, draw from N the point in which it meets the circumference of the circle Q E R, N O perpendicular to AB, so that A O may be the cosine of N A O, and from O toward A take O P = A B, then A P will be the cosine of the angle A B E′; so, to find B E′, draw P Q perpendicular to A P, meeting the circle in Q; join A Q, and draw B E′ parallel to A Q, meeting A E′ in E′; the point E′ is in the curve. In this way the other points of the curve may be found.

"The curve will pass through B, and will cut A B at an angle of which the cosine = R B. If then E be such, that A E = A B, the curve will cut A B at right angles. If E″ be more remote from A, the curve will make with A B an obtuse angle toward D; in other cases it will make with it an acute angle.

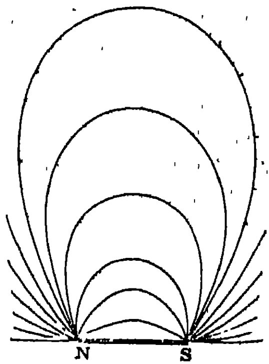
"A construction somewhat more expeditious may be had by describing the semicircle A F B, cutting A E in F, and A E′ in N, and describing a circle round A with the distance A L = 2 A F, cutting A E′ in *b*. If B G be applied in the semicircle A F B = N *b*, B G must cut A N in a point E′ of the curve, because A N + B G = 2 A F, and A N and G B are cosines of the angles at A and B.

"As the lines A N and B G may be applied either above or below A B, there is another situation of their intersection E′. Thus A *n* being applied above, and B *g* below, the intersection is in *e′*. The curve has a branch extending below A; and if D *e* be made = D E, and B *e* be drawn, it will be an asymptote to this branch. There is a similar branch below B. But these portions of the curve evidently suppose an opposite direction of one of the two magnetic forces, and therefore have no connection with the position of the needle."*

* Robison's *Mechanical Philosophy*, vol. iv. p. 350-3.

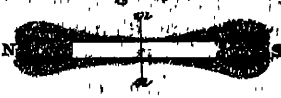
The general form of the magnetic curves is shewn in fig. 46. where they are seen *converging* to the two poles N S of the magnet N S, and changing their form with their distance from the magnet.

Fig. 46.



We have already stated that iron filings, arranged by the action of a powerful magnet, afford the finest experimental illustration of the magnetic curves. The best way to do this is to stretch a sheet of paper tightly over a wooden frame, and place it horizontally immediately above a powerful bar magnet lying on the table. Fine iron filings are now to be shaken through a gauze bag upon the surface of the paper. When the filings are thrown into a state of agitation by gently tapping upon the paper frame, they will dispose themselves into regular lines, stretching from one pole of the magnet to the other, and following the course of the magnetic curves, and exhibiting them beautifully to the eye. This effect is shewn in the annexed figure, where N S are the poles of the magnet N S, *m n* being the mean line where no filings adhere. The same arrangement is also produced when the magnet is held above the paper containing the filings.

Fig. 47.



In the case of induced magnetism, the steel filings arrange themselves in curves round the iron on which the magnetism is induced, as shewn in fig. 48, where the small bar of iron is in contact with the north pole N of

a magnet, *m n* being the mean line which separates the two opposite actions of the little iron bar. When the little bar of iron is placed at a distance from the magnet N, as in fig. 49, the filings arrange themselves as in that figure, *m n* being the mean line as before.

Fig. 48.

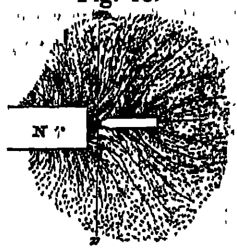
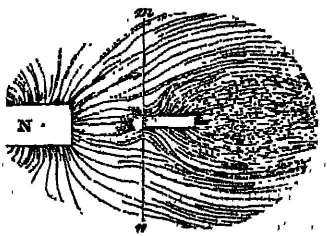


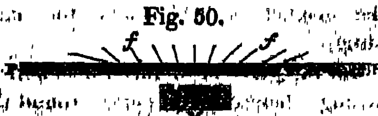
Fig. 49.



Dr Roget has given the following interesting account of the phenomena which take place by continuing to agitate the filings when they are arranged as in fig. 50.

"By continuing to tap upon the paper," says he, "the filings arrange themselves still more visibly into separate lines; but here a curious and perhaps unlooked-for phenomenon presents itself. The lines gradually move and recede from the magnet, appearing as if they were repelled instead of attracted, as theory would lead us to expect. This arises from the circumstance that each particle of iron, or cluster of particles, is thrown up into the air by the shaking of the paper, and, while unsupported, immediately turns on its centre, and acquires a position more or less oblique to the plane of the paper. This is shewn in fig. 50, in which M represents a section of the magnet, P P a section of the paper, and *f f* the position of the filaments of

Fig. 50.

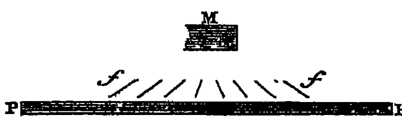


iron thrown up into the air. The end of each filament nearest to the magnet is thus turned a little downwards,

and the filament falls upon the paper at a point a little more distant than that which it before occupied; and thus, step by step, it moves farther and farther from the magnet, till it reaches the edge of the paper, and falls off.

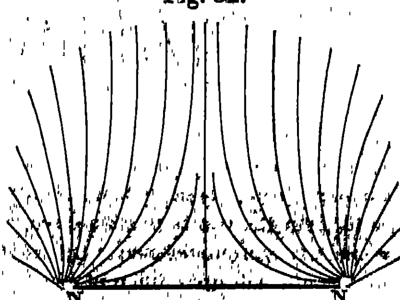
"When the magnet, instead of being beneath the paper, is held above it, the effect is just the reverse. In this latter case, the lower ends of the filaments having a tendency to turn towards the magnet, the filings gradually collect under it, when made to dance by the vibrations of the paper, instead of falling outwards as they did before. This will be seen from fig.51, where the letters have the same indications as in the preceding figure."*

Fig. 51.



A different set of magnetic curves is produced when two similar poles, for example two north poles, as shewn in the annexed figure, are placed near each other. These curves are called *divergent* curves, and may be exhibited by iron filings like the convergent ones.

Fig. 52.

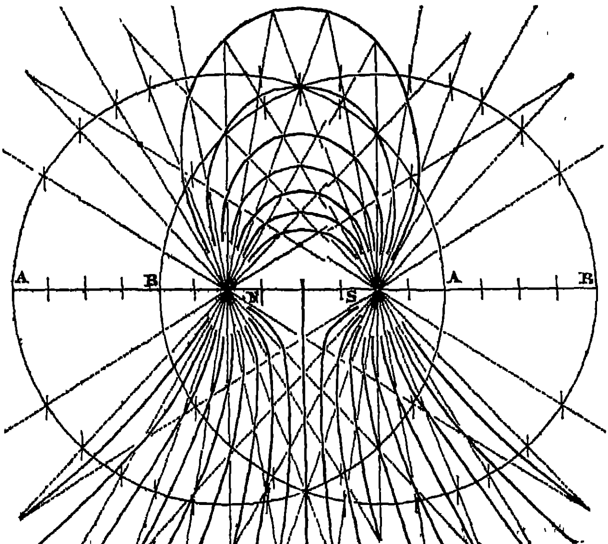


Dr Roget has given the following expeditious method of delineating a great number of magnetic curves, related to the same distance between the two magnetic poles. He

* *Library of Useful Knowledge*, art. *Magnetism*, p. 21.

describes from each pole N S, as centres, the equal of circles or semi-circles A A, B B, with as large a radius as the paper will allow; and dividing the axis produced till

Fig. 53.



it meets both circles, he marks off, on the circumferences of both circles, the points where they are cut by perpendiculars from these points of division; then, drawing radii from the centre of each circle to the divisions of its respective circumferences, the mutual intersections of these radii will give different sets of points indicating the form of the magnetic curves which pass through them. These curves are, in the present case, composed of a succession of diagonals of the lozenge-shaped interstices formed by the intersecting radii, as shewn from *convergent* curves in the upper half of the figure. In the case of *divergent* curves in fig. 52, we must take the other diago-

nals of the lozenge-shaped intervals between the intersecting radii; that is, the diagonals which cross those constituting the convergent curves. This is shewn in the lower half of the figure.

The curves which are formed when the north and south poles of two magnets are placed near each other, as in fig. 43, enable us to explain the phenomena discovered by Dr Robison, and described in the preceding section. The following is the explanation given by that eminent philosopher. (See fig. 43.)

"Let NHM, NEL, be two magnetic curves, belonging to A; that is, such that the needle arranges itself along the tangent of the curve. Then the magnet B has two curves SGK, SEI, perfectly equal, and similar to the other two. Let the curves NHM, and SGK, intersect in C and F. Let the curves NEL, and SEI, touch each other in E.

"The needle being placed at C, would arrange itself in the tangent of the curve KGS, by the action of B alone, having its north pole turned toward the south pole S of B. But, by the action of A alone, it would be a tangent to the curve NHM, having its north pole turned away from N. Therefore, by the combined action of both magnets, it will take neither of these positions, but an intermediate one, nearly bisecting the angle formed by the two curves, having its north pole turned toward B.

"[illegible] the needle to F. Then, by the action of [illegible] would be a tangent to the curve [illegible] By the action of [illegible] north pole [illegible] A. By their joint action, [illegible] nearly bisecting the angle GEM, [illegible] pole toward A. Let the needle be placed [illegible]. Then by the action of the magnet A, it would be a tangent to the curve NEL, with its north pole pointing to E. But, by the action of B, it will be a tangent to SEI, with its north pole pointing to D. These

actions being supposed equal and opposite, it will have no verticity, or will be neutral, and retain any position that is given to it.

"The curve SEI intersects the curve NHM in P and Q. The same reasoning shews, that when the needle is placed at P, it will arrange itself with its north pole in the angle SPH; but, when taken to Q, it will stand with its north pole in the angle EQM.

"From these facts and reasonings we must infer, that, for every distance of the magnets A and B, there will be a series of curves, to which the indefinitely short needle will always be a tangent.

They will rise from the adjoining poles on both sides, crossing diagonally the lozenges formed by the primary or simple curves, as in fig. 43. These may be called compound or secondary magnetic curves. Moreover, these secondary curves will be of two kinds, according as they pass through the first or second intersections of the primary curves, and the needle will have opposite positions when placed on them. These two sets of curves will be separated by a curve GEH, in the circumference of which the needle will be neutral. This curve passes through the points where the primary curves touch each other. We may call this *the line of neutrality* or inactivity.

"We now see distinctly the effect of bringing the magnets A and B nearer together, or separating them farther from each other. By bringing them nearer to each other, the point E, which is now a point of neutrality, may be found in the *second* intersection (such as F) of two magnetic curves, and the needle will take a sub-contrary position. By drawing them farther from each other, E may be in the *first* intersection of two magnetic curves, and the needle will take a position similar to that of C.

"If the magnets A and B are not placed so as to form

a straight line with their four poles, but have their axes making an angle with each other, the contacts and intersections of their attending curves may be very different from those now represented; and the positions of the needle will differ accordingly. But it is plain from what has been said, that if we knew the law of action, and consequently the form of the primary curves, we should always be able to say what will be the position of the needle. Indeed, the consideration of the simple curves, although it was the means of suggesting to the writer of this treatise the explanation of those more complicated phenomena, is by no means necessary for this purpose. Having the law of magnetic action, we must know each of the eight forces by which the needle is affected, both in respect of direction and intensity; and are therefore able to ascertain the single force arising from their composition.

"When the similar poles of A and B are opposed to each other, it is easy to see that the position of the needle must be extremely different from what we have been describing. When placed anywhere in the line DF, between two magnets, whose north poles front each other in N and S, its north pole will always point away from the middle point D. There will be no neutral point E. If the needle be placed at P or Q, its north pole will be within the angle EPH, or FQI. This position of the magnets gives another set of secondary curves, which also cross the primary curves passing diagonally through the lozenges formed by their intersection. But it is the other diagonal of each lozenge which is a chord to those secondary curves. They will, therefore, have a form totally different from the former species."

CHAPTER IX.

ON TERRESTRIAL MAGNETISM.

We have already seen, in preceding chapters, that a magnetic bar or needle, when either suspended by a thread, or at liberty to move freely upon a pivot, will, when all other magnetic bodies are entirely removed from it, settle in a fixed position, which in this country, is about 25° to the west of north; this deviation of the needle from the north is called its *variation*. The very same thing will take place if a magnet or magnetized needle is placed on a piece of cork, and made to float on any fluid surface. The magnetic force by which the magnetic needle is thus made to take a fixed direction, and to return to it when it is pushed aside from that direction, has been naturally supposed to reside in the earth, and hence it has been called *terrestrial magnetism*.

But not only is a magnetized body *directed* in this manner by some unseen power; an unmagnetized body, such as a piece of iron, may be rendered permanently magnetic by the same power. This phenomenon is said to have been first observed in the vertical rod of the weather-cock of the church of the Augustines at Mantua, though others have ascribed the discovery of the fact to Gassendi. This rod had become magnetized by the continued action of the invisible power of which we speak. In later times it has been observed, that a bar of soft iron is, by the influence of the same power, converted into a temporary magnet, with a north and south pole, when it is placed in the direction which a magnetic needle assumes, and is inclined to the horizon.

If, in place of suspending the needle, or making it move horizontally on a pivot, we take an unmagnetized needle, and balance it upon a horizontal axis, then it will of course lie horizontally; but if we magnetize the needle, we shall find that it no longer remains horizontal, but takes an inclined position, or *dips*, as it is called; the *dip*, or the inclination downwards from a horizontal line, being about 70° in this country.

If we now take a magnetic needle, and suspend it by a silk fibre, we shall find, that when it is pushed out of its position of rest, it will perform a certain number of oscillations in a given time before it again takes a fixed position. When this observation is made in different latitudes, it is found that the needle is brought to rest sooner in some places than in others; which proves that the intensity or strength of the magnetic force which directs the needle to the north varies in different latitudes. Hence we have to consider three important classes of phenomena in reference to terrestrial magnetism:

1. The variation or declination of the needle, and its laws;
2. The dip or inclination of the needle;
3. The intensity of terrestrial magnetism;

of which we shall treat as perspicuously and fully as the nature of the subject and our confined limits will permit.

Sect. I.—On the Variation of the Needle.

A general account of the phenomena of the variation of the needle has been given in the order of their discovery in the historical part of this article. We shall now proceed to give a more minute account of them.

Measures of the variation of the needle have been taken by navigators and travellers in every part of the globe. Putting aside the inaccuracies common to them all, arising

from the imperfect instruments which were in many cases employed, the observations made on ship-board were particularly liable to error, owing to the action which the iron on board exercised upon the compass.

The first person who attempted to collect and generalize the immense number of observations which had been made on the variation of the needle was Dr Halley, who published them in a sea-chart in 1700, in which he traced lines through all the parts of the globe where the variation was 0°, 5°, 10°, &c. These lines, which have since been called the *Halleyan lines* or *curves*, excited great interest, and had the advantage of giving, at one glance, an ocular picture of the phenomena in every part of the world. As this *Variation Chart*, however, soon became old, from the rapid changes in the variation, as well as from confused methods of observation, Messrs Mountain and Dodson collected, from the records of the Admiralty, and from the papers of various naval officers, about 50,000, which they laid down in variation charts for 1745 and 1756.

The next step in the generalization of the phenomena of variation was made by Mr Churchman, who published, in 1794, a programme of a *Magnetic Atlas*. He refers his variation lines to two poles, one of which he places, for the year 1800, in latitude 58° north, and longitude 134°, west of Greenwich, very near Cape Fairweather; while the other pole is in latitude 58° south, and longitude 165° east of Greenwich. He supposes the northern pole to revolve in 1096 years, and the southern one in 2289 years.

It is to Professor Hansteen, however, that we are indebted for the most satisfactory collection of observations on the variation of the needle, and for the most philosophical generalization of them. In the Magnetic Atlas which accompanies his work on the magnetism of the earth, he has published a variation chart for 1787, in

which the irregularities and inflexions of the curves, and their total want of symmetry, prove how irregular are the causes on which terrestrial magnetism depends. In this chart, the *western line of no variation*, or that which passes through all the places on the globe where the needle points to the true north, begins in latitude 60°, to the west of Hudson's Bay, proceeds in a south-east direction through the North American lakes, passes the Antilles and Cape St Roque, till it reaches the south Atlantic Ocean, where it cuts the meridian of Greenwich in about 65° of south latitude. This line of no variation is extremely regular, being almost straight till it bends round the eastern part of South America a little south of the equator. The *eastern line of no variation* is extremely irregular, being full of loops and inflexions of the most extraordinary kind, indicating the action of local magnetic forces. It begins in latitude 60° south, below New Holland, crosses that island through its centre, extends through the Indian Archipelago with a double sinuosity, so as to cross the equator three times, first passing north of it to the east of Borneo, then returning to it and passing south between Sumatra and Borneo, and then crossing it again beneath Ceylon, from which it passes to the east through the Yellow Sea. It then stretches along the coast of China, making a semicircular sweep to the west till it reaches the latitude of 71°, where it descends again to the south, and returns northwards with a great semicircular bend, which terminates in the White Sea. These lines of no variation are accompanied through all their windings by other lines where the variation is 5°, 10°, 15°, &c. these last lines becoming more irregular as they recede from those of no variation. In the South Pacific Ocean, and the equatorial part of the North Pacific, they are so little dependent on the lines of no variation, that they form returning curves of an elongated oval form, the curves of 2°, 3°, 4°, 5°, 6°, and 7°, crossing the equator and the tropic of Capricorn

twice, so that, in the centre or axis of the ovals which these lines form, there should be a fragment of a line of no variation.

The great changes which had taken place in the variation since 1787, and the number of new observations which had been made in every part of the world, induced Professor Barlow, in 1833, to construct a new variation chart, which forms a very interesting and valuable record of the present state of our knowledge on this subject.* With the kind permission of Professor Barlow, we have given a reduced copy of this chart in Plate CCCXXVII., and have included in it his separate polar projection of the variation lines within the arctic zone. When compared with the account given above of the two lines of no variation in Hansteen's chart, the motion of these lines, and of the whole system, will be distinctly seen.

In the charts both of Hansteen and Barlow the variation lines exhibit a convergency at their extremities; † and Hansteen considers it proved that there are *four points of convergency*, two in each hemisphere, a weaker and a stronger, on opposite sides of the poles of revolution. These four points he considers as the *four magnetic poles* of the globe; and, by comparing observations which have been made at different times, he concludes that they have a regular motion round the globe, the two northern ones from west to east, in an oblique direction, and the two southern ones from east to west, also obliquely. The

* See *Philosophical Transactions*, 1833, p. 667—675, and plates xvii. and xviii.

† Professor Barlow has inserted the magnetic observations of Commander Ross; and he remarks, that the very spot where this officer found the needle perpendicular, "that is, the pole itself, is precisely that point in my globe and chart in which, by supposing all the lines to meet, the several curves would best preserve their unity of character, both separately and conjointly, as a system." The exact place of the pole is laid down in the accompanying chart, Plate CCCXXVII.

following are the periods of their revolution, as calculated from the best observations previous to 1817, when his work was published:

The *strongest* NORTH pole in 1740 years.
The *strongest* SOUTH pole in 4609 years.
The *weakest* NORTH pole in 860 years.
The *weakest* SOUTH pole in 1304 years.

Upon these data he computed the following table, shewing the position of these poles from 1800 to 1850:

	Strongest *North* Pole.		Strongest *South* Pole.	
Years.	West Longitude.	North Latitude.	East Longitude.	South Latitude.
1800	93° 33′	69° 53′	134° 8′	69° 7′
1810	91 28	69 45	133 21	68 59
1820	89 24	69 38	132 35	68 52
1830	87 19	69 30	131 47	68 44
1840	85 15	69 22	131 1	68 37
1850	83 10	69 14	130 14	68 29
	Weakest *North* Pole.		Weakest *South* Pole.	
Years.	East Longitude.	North Latitude.	West Longitude.	South Latitude.
1800	131° 43′	85° 25′	130° 28′	77° 50′
1810	135 54	85 18	133 14	78 3
1820	140 6	85 12	135 59	78 16
1830	144 17	85 6	137 45	78 29
1840	148 28	85 0	140 31	78 41
1850	152 40	85 0	143 16	78 54

Hansteen remarks, that the four periods above mentioned, viz. 860, 1304, 1740, and 4609, become by a slight alteration, 864, 1246, 1728, and 4320; and he adds, rather fancifully for a matter of science, that these numbers are equal to 2×432, 3×432, 4×432, and 10×432,

and that the number 432 is one of the most important among the sacred numbers of the Indians, Babylonians, Greeks, and Egyptians, which are said to depend on certain combinations of natural events. According to the mythology of the Brahmins, the duration of the world is divided into four periods; the first of which is 432,000 years; the second, $2 \times 432{,}000$; the third, and so in all $(1 + 2 + 3 + 4) = 10 \times 432{,}000$. Hansteen also considers it worthy of remark, that the sun's mean distance from the earth is 216 (the half of 432) radii of the sun, the moon's mean distance 216 radii of the moon, and, what he says is still more striking, $60 \times 432 = 25920$, the smallest number divisible at once by all the four periods; and hence, he adds, the shortest line in which all the four poles can accomplish a cycle, and return to the same state as at present, *coincides exactly with the period in which the precession of the equinoxes will amount to a complete circle*, reckoning the precession at a degree in seventy-two years.

Hansteen considers the four poles as originating in *two* magnetic axes, the two strongest being the termination of one axis, and the two weakest of the other; and he conceives that they may have been produced either along with the earth itself, or at a later epoch. According to the first supposition, it is not easy to account for their change of position; but according to the last, they must have originated either from the earth alone, or from some external cause. If they originated in the earth, their change of position is still unsusceptible of explanation; and hence Hansteen conceives that they have their origin from the action of the sun heating and illuminating the earth, and producing a magnetic tension, as it produces electrical phenomena.

Since the publication of Professor Hansteen's work, the valuable observations made during the British voyages of discovery in the arctic regions have been given to the

world; and by availing himself of these, and obtaining access to others unpublished in the marine chart office at the Admiralty, the Norwegian philosopher has obtained more accurate determinations both of the positions and periods of revolution of the magnetic pole. The following is a brief abstract of his calculations.

1. *Strongest north pole.* In 1813 the observations made on board his majesty's ship Brazen, in Hudson's Bay, give 67° 10′ for the latitude of the strongest north magnetic pole, and 92° 24′ for its west longitude. Hence by comparing this with previous determinations we have

	Latitude of Pole.	West Longitude of Pole.
1730	70° 45′	108° 6
1769	70 17	100 2
1813	67 10	92 24

From these data we obtain the motion of the pole to the east.

Epochs.	Years.	Change of Place in Longitude.	Annual Motion.
From 1730 to 1769	39	8° 4′	12′ 44″
1769 to 1813	44	7 38	10 41

From which we obtain

Mean annual motion of the pole................11′ 4″·25

Period of complete revolution.................1890 years.

In August, 1819, Captain Parry was to the north of this pole, and found the dip to be 88° 37′, and on the 11th September he was three degrees west of the pole. Hence, as his latitude was then 74° 27′, the latitude of the pole must have been about 71° 27′.

According to the more recent observations of Commander Ross, this pole, upon which he erected a flag, is situated in north latitude 70° 5′ 17″, and west longitude 96° 45′ 48″, which coincides strikingly with Hansteen's result.

2. *Strongest south pole.* By combining the observations of Cook in 1773 and 1777, with those of Furneaux in 1773, and comparing these with Tasman's observations in 1642, Hansteen has found the following position of it.

	Motion in 131 Years.
1642, north lat. 71° 5′; east long. 146° 57′	10° 14′
1773, north lat. 69° 26′ 5″; east long. 136° 15′4″	

Hence the real motion of this pole in 131 years is 10° 14′, or 4′·67 annually, and its period of complete revolution will be 4605 years.

3. *Weakest north pole.* By comparing observations made in 1770 and 1805, at Tobolsk, Tara, and Udinsk, in Siberia, Professor Hansteen found—

	North Latitude.	East Longitude.	Motion in 35 Years.	Annual Motion.
1770,	85° 46′	91° 29′ 30″	14° 35′	35′·128
1805,	85 21½	116 19		

Hence this pole completes its revolution from east to west in 860 years.

4. *Weakest south pole.* By comparing observations made by Cook and Furneaux in 1774, with those recorded by Halley as made in 1670, Hansteen obtained the following results:—

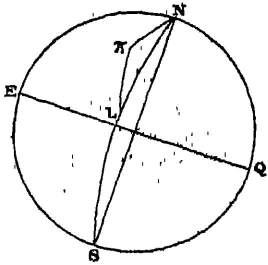
	South Latitude.	West Longitude.	Motion in 104 Years.	Annual Motion.
1670,	64° 7′	94° 33½′	28° 43½′	16′·57
1774,	77 17	123 17		

Hence this pole completes its revolution from east to west in 1308 years.

Professor Barlow has endeavoured to deduce the position of the magnetic pole, upon the supposition that the magnetic phenomena of the earth are analogous to those

exhibited by a simple iron ball. The tangent of the dip being equal to double the tangent of the magnetic latitude, Mr Barlow supposes ϖ to be the magnetic pole, N S the terrestrial poles, and L a known place where the dip and variation have been well ascertained. Then by the dip we obtain the magnetic latitude ϖ L; N L being the terrestrial latitude, and N L ϖ the variation. Hence, in the spherical triangle N L ϖ, we have two sides and the contained angle to find the side N ϖ the terrestrial latitude of the magnetic poles, and ϖ N L the longitude of the same pole, in reference to the meridian N L.

Fig. 54.



In making this computation, Mr Barlow selected a certain number of the best observations on the dip and variation of the needle, made in different parts of the world, and he obtained the following results:—

Place of Observation.	Date.	Dip.	Variation.	Computed Place of Magnetic Pole. North Lat.	Computed Place of Magnetic Pole. West Long.
Tristan d'Acunha	1821	37° 53′ S.	12° 0′ W.	70° 56′	46° 35′
Trinidad	1821	10 27 N.	5 0 W.	73 59	47 20
St Jago	1820	48 0 N.	15 55 W.	69 37	67 4
Teneriffe	1820	58 22 N.	20 47 W.	69 49	69 14
Madeira	[illegible]	63 47 N.	23 7 W.	68 4	65 26
Madrid	1799	67 41 N.	19 59 W.	72 47	[illegible] 38
Paris	1814	69 36 N.	22 34 W.	75 31	67 4
London	1818	70 34 N.	24 30 W.	75 2	67 41
Berlin	1805	69 53 N.	18 2 W.	79 2	70 44
Copenhagen	1818	71 20 N.	18 22 W.	79 43	67 38
Davis' Straits	1820	83 48 N.	60 20 W.	67 37	94 26
Regent's Inlet	1820	88 26 N.	118 16 W.	71 10	98 16
Baffin's Bay	1820	84 30 N.	82 2 W.	71 18	97 8
Possession Bay	1820	86 4 N.	108 46 W.	69 40	99 10
Melville Island	1820	88 43 N.	127 46 E.	73 12	102 46

Among these results there is a discrepancy of no less than 55° in longitude, and 10° in latitude; and hence Mr Barlow concludes that every place has its particular polarizing axis, which probably in all cases falls within the frigid zones, varying within these limits through all possible degrees of latitude and longitude.

These aberrations Mr Barlow ascribes to local inequalities in the distribution of the ferruginous parts of the terrestrial sphere.

The following tables contain the best measures of the variation of the needle. Table XI. containing the observations collected by Hansteen since the publication of his work, was communicated to the writer of this treatise by that eminent philosopher.

TABLE I.—*Containing the Variation of the Needle, as observed in Denmark, Norway, and Sweden.*

Names of Places.	Year of Observation.	Magnetic Variation.
Arendal,	1796	20°21′ W.
Arboga,	1799	17 25
Avestad,	1799	17 40
Bergen,	1768	19 20
	1791	24 45
	1792	25 30
Bommel Island,	1792	24 52
Bessested,	1780	34 30
Christiansund,	1768	16 30
Christiansand,	1794	22 0
Christiania,	1761	15 15
	1769	16 45
	1816	20 15
	1817	20 3
Carlberg,	1799	17 5
Carlscrona,	1716	11 15
Copenhagen,	1649	1 30 E.
	1672	3 35 W.
	1730	10 37
	1770	15 32
	1782	17 41
	1806	18 25
	1817	18 5
	1817	17 55½
Drontheim,	1761	13 50
	1786	19 0
Dyrefiords Haven,	1786	42 41
Fahlun,	1799	18 45
Flekkeröe,	1783	19 29
Fredericksborg,	1810	18 50
Gottenburg,	1694	8 30
	1748	12 40
Havnefiord,	1786	35 21
Holmenshavn,	1786	43 9
Hammerfest,	1765	6 50
Hustappen Island,	1766	7 0
Hvalöers Church,	1768	16 25
Hveen Island,	1672	2 35
Helsingöer,	1761	14 0
Hedmora,	1748	9 10
Jukasjorwi,	1776	11 30
Kielvigs Church,	1766	5 30
Karasjok,	1768	6 50
Kongswinger,	1779	17 30
Kullens,	1803	21 0
Köping,	1799	17 15
Nya Kopparberget	1799	17 25

Names of Places.	Year of Observation.	Magnetic Variation.
Kongsör,	1746	9°30′ W.
Kusamo Church,	1776	5 30
Lindesness,	1605	7 10 E.
Lofoeden Isles,	1608	0 0
	1609	0 0
Lund Pfarrhof,	1785	19 30 W.
Lyderhorn,	1768	19 20
Lindesberg,	1746	9 36
North Cape,	1769	6 0
Nora,	1799	18 35
Norrberke,	1799	17 35
Orebroe,	1799	17 7
Patrixfiord,	1772	33 30
Rust Island,	1613	4 8 E.
Stavanger,	1794	22 26 W.
Skudesness,	1613	8 0 E.
Stadthuk,	1768	19 10 W.
	1790	25 45
Stockholm,	1718	5 37
	1771	13 4
	1800	16 20
	1817	15 34
Salberg,	1746	9 0
Sala,	1799	16 0
Söderbärke,	1746	9 15
Sälö Bak,	1804	18 30
Sädankyla,	1776	5 30
Skiervoens Church	1768	16 30
Strömstad,	1804	18 0
Sulen Island,	1791	27 15
Talvig,	1766	6 50
Torneo,	1695	7 0
	1786	5 5
	1767	8 50
	1777	11 45
Utsjoki,	1748	8 30
Upsal,	1718	5 37
	1746	8 45
Uhma Capel,	1762	10 45
Uranienburg,	1672	2 35
Wardhus,	1748	0 0
		0 30
	1775	5 32
Vadsöe,	1816	7 55
Vangs Church,	1798	19 50
Vesterås,	1799	17 50
Vinga Båk,	1804	19 0

Table II.—*Containing the Variation of the Needle in Russia.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Awatscha Bay,	1805	5°39′ E.	Nizni-Udinsk,	1735	3°15′ W.
Barrannoi Kamen,	1787	17 40		1805	2 40 E.
Barnaul,	1770	2 45	Nertchinsk,	1735	3 0 W.
Casan,	1761	2 25 W.	Neschin,	1779	10 0
	1805	2 2 E.		1782	10 0
Catharinenburg,	1761	0 50	Orenburg,	1769	3 30
	1805	5 27			3 20
Carchow,	1783	7 27 W.	Orsk,	1769	0 15
	1811	5 17	Orel,	1781	9 0
Cherson,	1782	10 10	Petersburg,	1726	3 15
Caffa,	1772	7 0		1782	7 30
Dmitrewsk,	1771	5 49		1812	7 16
	1773	6 30	Perm,	1805	1 10 E.
Druia,	1778	10 40	Petropaulowska,	1779	6 19
St Elizabeth,	1770	9 45		1805	5 20
Gluchow,	1770	5 30	Petrosawodsk,	1785	5 9 W.
Gurief,	1769	3 35	Ponoi,	1769	1 10 E.
Gloubouca,	1615	18 0	Peczora,	1611	22 30 W.
Jakutskoi,	1768	5 15	Pustozerskoi,	1614	20 0
	1769	5 0	Revel,	1751	7 30
	1788	2 0	Riga,	1750	8 0
Irkutsk,	1735	11 5	Samara,	1770	8 10
	1805	0 32 E.	Sietscha,	1770	9 15
Jarewslawl,	1782	4 0 W.	Sisran,	1770	5 50
Jenicola,	1785	7 15	Selenginsk,	1735	0 30
Kola,	1769	1 45	Saratow,	1773	8 28
Krementschuk,	1770	8 0	Sewastropol,	1785	11 18
Krasnojarsk,	1785	2 0	Tscherkask,	1770	5 50
Kiachta,	1735	3 0	Tara,	1805	6 6 E.
	1735	2 45	Tomsk,	1805	5 37
Kiow,	1773	9 15	Tobolsk,	1716	0 0
Kaluga,	1784	7 45		1761	3 46
Kursk,	1784	5 0		1805	7 9
Kostroma,	1782	3 45	Tanbow,	1784	5 45 W.
Kesloff, or Kozlov,	1785	11 38	Umba,	1769	3 30
			Ufa,	1769	1 30 E.
Lubny,	1782	9 5	Ustkamenogorskoi,	1770	2 0
Moscow,	1782	5 26	Wologda,	1785	8 52 W.
Mosdok,	1785	6 40	Woronetz,	1788	8 0
Nezhni Kovima,	1787	14 40 E.	Zarisin,	1770	4 50

TABLE III.—*Containing the Variation of the Needle in Holland, Prussia, the Netherlands, and Switzerland.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Antwerp,	1600	9° 0′ E.	Konigsberg,	1628	1° 0′ W.
Amsterdam,	1767	17 30 W.		1642	1 5
Augsburg,	1772	16 40		1774	13 30
	1798	18 26	Leipsic,	1749	13 0
Berlin,	1717	10 42	Manheim,	1776	19 48
	1780	16 48		1785	19 44
	1805	18 2		1786	19 53
Bonne,	1782	17 20		1787	20 2
	1788	18 55		1788	20 5
Dantzig,	1628	1 0	Mittau,	1783	10 52
	1760	11 0	Middleburg,	1786	21 14
	1811	18 48		1788	21 56
Dusseldorf,	1788	20 0	Nuremberg,	1685	5 5
Dresden,	1797	18 30	Prague,	1774	15 45
Freyberg,	1769	15 40		1787	17 20
Frankfort-on-Maine,	1774	16 32	Rotterdam,	1767	19 0
			Regensburg,	1784	17 49
Franeker,	1771	19 30		1786	19 11
	1773	18 30	Tübingen,	1747	13 34
Geneva,	1797	19 40		1752	14 37
	1804	21 13	Tankermund,	1814	19 0
Grätz,	1770	15 50	Vienna,	1638	0 0
Göttingen,	1777	16 48		1760	13 0
Hague,	1782	20 16	Wurtzburg,	1781	18 40
Inspruck,	1787	22 40 ?		1787	18 35
Konigsberg,	1600	0 0	Zurich,	1762	15 15

TABLE IV.—*Containing the Variation of the Needle, as observed in France.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Antibes,	1682	8°40′ W.	Montpellier,	1644	1°10′ W.
Bayonne,	1680	1 20	Ushant Island,	1776	23 1
Boulogne,	1767	17 26	Paris,	1541	7 0 E.
Brest,	1679	1 45		1580	11 30
	1771	20 10		1660	1 0
	1798	25 30		1667	0 15 W.
Calais,	1681	4 30		1700	7 40
	1767	19 30		1750	17 15
Dieppe,	1619	6 30 E.		1780	20 35
Dunkirk,	1767	18 33 W.		1800	22 12
Havre de Grace,	1767	19 15		1819	22 29
	1782	22 15	Royan,	1680	1 20
Marseilles,	1761	18 0	Toulon,	1682	2 45
	1798	20 55	Toulouse,	1747	15 10
St Maloes,	1681	2 0		1756	15 45

TABLE V.—*Containing the Variation of the Needle, as observed in Great Britain and Ireland.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Bristol,	1666	1°27′ w.	London,	1790	23°39′ w.
	1667	1 33		1800	24 3.6
Bushy Heath,	1813	24 22 17		1823	24 9 40
	1822	24 35 26	Plymouth,	Unknown.	13 24 E
Dublin,	1745	18 0 w.		1733	13 27 w.
	1791	27 23	Stromness Harbour,	1774	24 0
London,	1580	11 15 E.			
	1657	0 0 w.			

TABLE VI.—*Containing the Variation of the Needle, as observed in Portugal, Spain, and Italy.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Aranjuez,	1798	19°25′ w.	Lisbon,	1638	7°39′ E.
Alborne Island,	1733	14 12		1668	0 50 w.
Braga,	1761	16 15		1697	4 18
Brescia,	1676	4 0 E.		1782	19 51
Cadiz,	1724	5 25 w.	Loretto,	1756	15 35
	1769	17 15	Madrid,	1799	19 59
	1791	21 56	Malta,	1694	9 15
Cape St Vincent	1733	13 49			9 45
Cape St Gatt, Sp.	1733	13 56		1708	10 25
Cape St Mary's, P.	1784	14 20	Minorca, C. Mola,	1738	14 34
Cape Finisterre,	1589	7 40 E.	Padua,	1725	18 0
	1768	21 4 w.		1730	
C. St Antonio, S.	1792	19 28		1770	16 20
Ferrara,	1677	2 0	Rome,	1670	2 15
Gibraltar Bay,	1783	18 38		1730	11 0
	1761	17 11		1788	17 12
	1792	22 6			

TABLE VII.—*Containing the Variation of the Needle, as observed in Turkey in Europe.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Akiermann,	1771	9°25′ w.	Constantinople,	1694	9° 0′ w.
Bender,	1772	9 45			12 0
Bucharest,	1772	11 36	Ofen,	1781	16 45
Constantinople,	1600	0 0		1788	16 36
	1625	2 0			

TABLE VIII.—*Containing the Variation of the Needle, as observed in Asia and the adjacent Islands.*

Names of Places.	Year of Observation.	Magnetic Variation.
Alexandretta, Syria,	1694	14°22′ W.
Aden, Arabia,	1612	13 40
	1612	12 40
	1674	15 0
	1723	13 50
	1723	13 42
Ava, India,	1689	5 0
Aleppo, Syria,	1781	12 30
Alguarda, near Goa	1722	5 49
Anjanga, India,	1724	4 17
Bab-el-Mandeb,	1723	14 20
	1723	14 8
Baixos de Chagos Island,	1610	19 50
Beit-el-Fakih,	1762	11 50
Bachian Island, Amasane Bay,	1612	4 48 E.
Bombay, India,	1676	12 0 W.
	1751	5 12
	1721	5 16
	1722	5 7
	1723	5 10
Banca Island,	1791	0 0
Balasore, India,	1680	8 20
Do. Cape Palmiras,	1722	3 33
Calicut,	1722	4 5
	1772	4 9
Canton,	1690	2 25
	1722	1 30
Carwar Bay, India,	1722	5 40
	1722	5 4
	1723	5 8
	1724	5 32
Celebes, Bonthain,	1767	1 16
Chaul, India,	1721	5 27
Cape Comorin, India,	1601	16 0
	1620	14 20
	1680	8 45
	1688	7 30
	1728	2 51
Ceylon, Friar's Hood,	1722	2°12′ W.
	1722	2 21
Point de Galle,	1618	13 24
	1723	2 46
	1723	2 45
Chandernagore, India,	1781	3 0
	1750	0 0
Cochin, India,	1614	15 0
	1724	4 16
Daman, India,	1612	16 30
Dabul, India,	1610	15 34
	1611	16 30
Derbent, Persia,	1712	12 0
Darsina, Arabia,	1612	15 2
Doy or Doa, Molucca Isl.	1618	5 20 E.
Firando, an isl. near Japan,	1618	2 50
Goa, India,	1609	16 0 W.
	1724	5 41
Guadel Cape, Persia,	1618	17 15
	1616	18 0
Hainan Isl. China,	1618	0 50
Hyderabad, 27th June,	1804	1 16·39 E.
Java, Bantam,	1609	3 0 W.
Java, Batavia,	1767	1 25
	1768	0 25
Java, Palimbang,	1605	3 20
Ispahan, Persia,	1787	7 30
Iriseh,	1797	8 14
Ingana Island,	1607	4 13
Jask Cape, Persia,	1616	19 20
Judda, Arabia,	1769	11 52
	1776	12 55
Kasbin, Persia,	1787	7 33
Kerguelen's Land,	1776	27 44
Louveau, Siam,	1685	4 45
	1685	0 30
	1686	4 45
	1688	4 30

TABLE VIII.—*continued.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Lucepara Island,	1767	0° 0′ w.	Prince's Island, near Java,	1767	1° 0′ w.
Macao,	1616	1 30		1780	0 54
	1779	0 32	Pulo Condore Island,	1620	1 0
Madras, India,	1722	2 52		1780	0 14
	1723	3 16	Pekin,	1755	2 0
Madura Island, near Java,	1768	0 30	St Paul's Island,	1677	23 30
			Roquepiz Island,	1610	23 30
Mangalore, India,	1722	5 24	Rogipore (Rajapur,)	1722	4 58
	1722	5 25			
	1723	5 5	Rasalgat Cape, Arabia,	1618	19 20
Masulipatam, India,	1610	12 22	Sually,	1610	16 40
Machian Island, near Gilolo,	1612	4 12 E.		1611	16 30
	1618	3 38		1612	17 0
Maldevische Canal,	1605	17 0 w.	Sunda Strait,	1615	3 30
	1722	4 16	Sinde,	1613	16 45
Mazeira Island, Arabia,	1613	20 10	Sinope,	1797	10 18
			Surat,	1611	16 23
Mocha, Arabia,	1723	13 24		1723	5 22
	1769	12 38	Singanfu, China,	1689	3 17
	1776	11 20	Sumatra,		
Mindanao, Cape St Augustin,	1767	1 45 E.	Achen,	1610	6 15
			Marlborough Ft.	1794	1 10 E.
			Priaman,	1795	1 8
Nankin, China,	1685	0 0 w.		1612	4 10 w.
Nicobar, India,	1605	7 5		1613	4 50
Paliacate, India,	1611	13 15	Tellichery, India,	1722	4 21
	1618	13 10		1722	4 4
Patapilli, India,	1611	12 47	Tiiz,	1618	18 30
	1611	12 22	Tecu Island,	1612	4 40 E.
	1618	13 50	Xin-Yam, China,	1682	0 0 w.
Pondicherry,	1689	7 0	Ula, China,	1682	1 40 E.

TABLE IX.—*Containing the Variation of the Needle, as observed in Africa and the adjacent Islands.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Alexandria, Egypt,	1688	5° 45′ w.	Accara Fort, Guinea,	1726	11° 25′ w.
	1798	13 6		1726	14 53
Ascension, Isl.	1678	1 0 E.	Angoxa,	1611	12 1
	1754	8 6 w.	Ab-dal-Curia Island, west of Sowtora,	1612	17 23
	1775	10 52		1798	12 48
	1806	15 40			

TABLE IX.—*continued.*

Names of Places.	Year of Observation.	Magnetic Variation.
Algiers, Barbary,	1731	14° 0′ W.
Azore Islands.		
Fayal Bay,	1589	8 5 E.
	1775	22 7 W.
Flores,	1600	0 0
Marie,	1610	1 40 E.
Bab-el-Mandeb,	1723	14 20 W.
	1723	14 8
Baxos de Chagos,	1610	19 50
Bourbon, Isle of, Mascarenhas,	1614	22 48
St Paul's Bay,	1722	19 49
	1722	19 44
Boobam,	1616	13 12
Cape Coast,	1726	11 55
	1726	12 10
	1726	11 46
Canary Islands.		
Ferro,	1724	5 0
	1769	17 30
	1802	19 55
Lanzarote,	1610	6 6 E.
Madeira, Funchal,	1727	6 58 W.
	1766	14 10
	1766	16 0
	1771	18 0
	1783	18 22
	1802	20 21
Grand Canary,	1610	6 6 E.
Teneriffe, Santa Cruz,	1769	15 43 W.
	1770	15 30
	1776	14 41
	1776	15 55
	1785	15 52
	1788	20 1
	1792	16 32
	1803	16 [illegible]
Comora Islands.		
Angoxa, on coast of Africa,	1611	18 0
	1721	19 12
	1721	19 44
	1721	20 33
Anjouan,	1722	20 30
	1722	20 33

Names of Places.	Year of Observation.	Magnetic Variation.
Mayotta,	1722	21° 12′ W.
	1722	20 24
Molalio,	1611	15 20
Cape Verd Islands.		
Porto Praya, St Jago,	1725	4 5
	1766	8 20
	1766	8 20
	1772	10 45
	1791	14 12
Mayo,	1725	8 32
	1776	9 32½
Sal,	1610	8 30 E.
Cairo,	1694	12 15 W.
	1761	12 25
	1762	11 40
	1798	12 0
Damietta, Egypt,	1694	12 30
Doara, Ajan,	1611	17 36
	1611	17 20
Prince Edward's Island,	1776	26 15
France, Isle of (Mauritius),	1609	21 0
	1722	18 46
	[illegible]	18 39
	[illegible]	19 7
	[illegible]	19 45
Cape of Good Hope,		
Cape l'Aguillas,	1609	0 12
Saldanha Bay,	1605	0 30 E.
	1614	1 30 W.
Simon's Bay,	1780	22 16
	1791	23 40
Table Bay,	1614	1 45
	1667	7 15
	1675	8 28
	1687	8 30
	1699	11 0
	1702	12 50
	1706	13 40
	1708	14 0
	1721	16 25
	1724	16 27
	1724	16 18

Names of Places.	Year of Observation.	Magnetic Variation.
Gorée,	1682	0° 0′ W.
	1769	12 15
	1772	10 30
Guardafui, Cape,	1610	17 35
	1728	12 34
Hermanas Isl. near Cape Guardafui,	1612	17 23
St Helena, Island of,	1600	8 0 E.
	1691	1 0 W.
	1806	17 18
Madagascar,		
Augustin's Bay,	1607	15 30
	1721	23 48
Antongill Bay,	1661	22 30
	1761	18 0
Fort Dauphin,	1661	19 0
	1761	22 7½
Foul Point,	1762	16 45
St Sebastian, Cape,	1600	18 40
	1722	18 36

Names of Places.	Year of Observation.	Magnetic Variation.
St Mary's Isl. near Madagascar,	1610	19° 50′ W.
	1722	19 53
Nosf-Gombi, an island near Madagascar,	1722	20 0
Salée Roads,	1735	12 19
Sierra Leone,	1608	1 50 E.
	1725	5 12 W.
Sunken Rocks, S. lat. 31° 48′,	1606	21 0
Socotra, Island of,	1611	16 0
	1776	8 6
St Thomas, Isle of,	1726	14 48
	1726	14 32
Tripoli,	1733	13 22
Trinidad Island, S. lat. 20° 45′ W. long. 29° 30′.	1615	12 0 E.

TABLE X.—*Containing the Variation of the Needle, as observed in America and the adjacent Islands.*

Names of Places.	Year of Observation.	Magnetic Variation.
Acapulco,	1744	8° 0′ E.
Albany Fort,	1730	25 0 W.
Antigua Island,	1774	17 0 W.
	1727	4 28 E.
	1761	4 31 W.
Augustin, Cape,	1670	5 30 E.
Bear Island,	1596	18 0
	1610	18 30
Beverley,	1781	7 4 W.
Barbadoes, Carlisle Bay,	1726	4 24 E.
	1761	3 47
Bastimento's Isle,	1726	7 48
Boston,	1708	9 0 W.
	1741	7 30
Button Isle,	1615	24 0
	1730	39 0

Names of Places.	Year of Observation.	Magnetic Variation.
Buenos Ayres,	1708	15° 32′ E.
Bahia, Brazil,	1708	4 30
Cambridge,	1708	9 0 W.
	1783	6 52
Cape Cathivas,	1726	7 24 E.
Carthagena,	1705	7 12
	1726	6 50
St Croix Island,	1788	3 20
St Christopher's, Basseterre,	1726	4 10
Cuba.		
Pau de Matansas,	1726	4 24
Havannah,	1732	4 30
Cayenne Island,	1672	11 0
	1682	5 30

TABLE X.—*Continued.*

Names of Places.	Year of Observation.	Magnetic Variation.
Conception,	1709	10°20′ E.
Coquimbo,	1700	8 32
Curaçoa,	1704	6 40
Cumana,	1799	4 14
Chesapeake Bay,	1732	4 58 W.
Cod Bay,	1789	6 45
Cape Christian, Greenland,	1605	12 15
St Catherine's Island,	1712	12 0 E.
	1785	12 0
	1804	7 51
Cape Corientes,	1684	4 28
Discovery Harbour,	1792	21 30
Desolation Sound,	1792	19 16
St Diego, California,	1792	11 0
Deseado Island,	1726	3 27
Domingo.		
Cape François,	1772	5 20
	1776	5 30
	1788	5 32
Alta Vela Island,	1728	6 2
Frio, Cape,	1670	12 10
Fernando Naronha,	1610	8 10
Florida, Cape,	1726	3 26
Fuego, Terra del.		
Christmas Sound,	1774	24 43
Good Success Bay,	1769	24 9
Godthaab, Greenland,	1784	50 30 W.
	1787	51 21
Guadaloupe,	1726	3 22 E.
Hermit Island,	1707	20 0
Juan Fernandez,	1767	11 0
Jamaica.		
Portland Point,	1726	6 2
Port Royal,	1726	4 31
Black River	1732	6 2
Jamba Point,	1726	6 20
Lima,	1709	6 15
Mexico,	1769	5 30

Names of Places.	Year of Observation.	Magnetic Variation.
Martinique,	1682	4°10′ E.
	1704	6 10
	1760	5 41
Marie Galante Island,	1726	3 40
St Martha, Cape,	1704	7 6
Massafuera Island,	1765	9 36
	1767	10 24
	1795	9 15
Mendocino, Cape,	1698	2 0
	1786	14 24
Moose Fort, Hudson's Bay,	1774	17 0 W.
Musquito Cove, Greenland,	1776	50 36
Monterrey,	1795	12 22 E.
Montserrat,	1765	5 32
Newfoundland, Fort St Pierre,	1772	19 15 W.
Nutka,	1778	19 45
	1792	18 22 E.
Norton Sound,	1778	25 45
Norriton,	1770	3 8 W.
Porto Bello,	1704	7 25 E.
Pisco,	1707	7 0
Paraibo,	1698	5 35
Quito,	1742	8 30
Quebec,	1649	16 0 W.
	1686	15 30
Rio Janeiro,	1768	7 34 E.
	1787	6 12
Resolution Island,	1615	24 6 W.
Savage Island,	1615	27 30
Smith's Sound,	1616	57 0
Santiago, Chili,	1794	14 28 E.
Sebalt Island,	1688	28 10
	1707	28 0
Spitzbergen.		
Bell Sound,	1613	18 11 W.
Cross Rheid,	1596	16 0
Horn Sound,	1610	16 0
	1613	12 37
Magdalon Sound,	1614	25 0
Poopy Bay,	1618	15 21

Table X.—*Continued.*

Names of Places.	Year of Observation.	Magnetic Variation.	Names of Places.	Year of Observation.	Magnetic Variation.
Read, Beach,	1596	16° 0′ w.	Valdivia,	1670	8°60′ e.
Vogelsang,	1773	20 38	Prince of Wales' Fort,	1725	21 0 w.
Unalashka Samganoodha Harbour,	1778	19 59 e.		1742	17 0
				1769	9 41
Vera Cruz,	1769	6 40	Ylo, Peru,	1710	6 38 e.
	1776	7 30	York, New,	1686	8 45
Valparaiso,	1709	9 30		1723	7 20
	1795	14 49		1789	4 20

Table XI.—*Containing the Variations of the Needle according to the latest observations.*

Names of Places.	Year of Observation.	Magnetic Variation.
I.—*Denmark, Norway, Sweden, and Finland.*		
Anholt Island, .	1788	19° 8′ w.
Abbo, Finland, .	Sept. 27, 1825	11 20
Brahestad, Finland,	Sept. 1825	10 38
Christiansand, .	Mar. 18, 1782	20 0
Christiania, . .	May 17, 1780	18 42
	Mar. 10, 1817	20 3
	May 24, 1822	19 47
Dagerort Island, .	1800	12 0
Fredriksteen, Norway,	Mar. 24, 1799	18 0
Jinnska Utön, . .	1800	13 0
Gran, Norway, .	1821	18 50
Hammerfest, .	1823	11 26
Gefleka Sandoe,	1800	14 40
Landsort, Sweden,	1800	15 20
Nortstaböe, Norway,	1821	22 12
Pitea, Sweden, . .	1825	10 6
Svarfvarort, Sweden, .	1800	13 40
Throndhjem, Norway,	July 28, 1825	19 36
Torneo, Finland, .	Aug. 1825	12 7
Ullensvang, Norway,	1821	22 51
Uleaborg, Finland, .	1791	10 0
	1825	9 32
Uloma, Cassel N. .	Sept. 1761	10 45
Wardoe, Norway, .	July 7, 1816	5 57
Wasa, Finland, .	Oct. 4, 1811	11 45
	Apr. 25, 1825	12 38

Names of Places.	Year of Observation.	Magnetic Variation.
	II.—*Russia.*	
Astracan,	April 17, 1580	13° 40′ W.
Archangelsk,	1800	0 30 W.
	1824	2 7 E.
Colmogro,	May 23, 1557	5 10 E.
Dog's-nose,	June 2, 1557	4 0 E.
Jokanskish Island,	1800	1 30 N.
	1824	1 7 E.
Kildin Island,	1824	1 2 W.
Krakau,	1821	14 30 W.
Matotschki, Nova Zembla,	1769	3 30 E.
	1824	10 34 E.
Oleniah Island,	1824	1 23 W.
Mestwa,	Aug. 1782	5 26 W.
	1790	3 47 W.
	1805	5 24 W.
Petersburg,	June 1817	7 15 W.
	Sept. 1818	7 27 5
Petzora,	July 17, 1556	3 30 W.
Seven Islands,	1824	0 30 W.
Tri Ostrowe Island,	June 16, 1557	3 30 E.
Udinsk,	1805	2 40 E.
Waigats Island,	1556	8 0 W.
	III.—*Germany, Netherlands, and Switzerland.*	
Aurich, Netherlands,	March, 1819	20 43 W.
	June, 1821	20 46½
	Sept. 1821	20 35
Berlin,	Oct. 14, 1825	17 40
Bentheim,	Nov. 11, 1817	19 41
Bocholt,	1822	20 58
Emden,	1816	20 42
Kilchehope,	Sept. 30, 1817	20 18½
Kremsmünster,	1815	17 20
	1820	[illegible]
	1824	16 26
Leipzig,	July 12, 1825	17 45
Meppen,	Sept. 11, 1817	20 37
Nordhorn,	Nov. 12, 1817	19 58
Wisens,	April, 1821	20 32
Wittmund,	July, 1821	20 36

TABLE XI.—*Continued.*

Names of Places.	Year of Observation.	Magnetic Variation.
	IV.—*France.*	
Brest, . .	1818	25° 7′ W.
Cherbourg, .	1818	26 47
Havre de Grace, .	Sept. 26, 1768	19 42
Lyons, . .	Nov. 1751	15 45
	Dec. 1755	16 30
	1761	18 45
Ouessant Island, .	Dec. 1806	26 45
Paris, . .	Oct. 12, 1816	22 25
	1819	22 29
	Oct. 3, 1829	22 12
Toulon, Cape Side, .	April 25, 1811	19 10
	V.—*England.*	
Edinburgh, .	Oct. 29, 1808	27 31·8
	Nov. 3, 1809	27 35·2
	Sept. 29, 1812	28 8·0
	July 9, 1823	27 48·0
Gravesend, . .	June 12, 1576	11 30 E.
Hermitage Hill, Leith,	1823	27 0 W.
London, . . .	June, 1806	24 8·6
	October, 1812	16·5
	June, 1816	17·9
	1820	11·7
	1828	9·8
Stromness, Orkney, .	June 3, 1819	27 50
	VI.—*Portugal, Spain, and Italy.*	
Alicante, .	Sept. 4, 1800	19 [illegible]
Aulona, .	1818	[illegible]
Barcelona, .	1785	18 [illegible]
Budua, .	1818	14 56
Cadiz, .	Oct. 29, 1768	19 12
Carthagena, .	March, 1789	18 45
	June 2, 1798	19 8
Cabrera Island, .	Sept. 29, 1789	19 0
Corunna, .	1806	20 47
Dulcigno, .	1818	15 53
Elba, .	June 15, ——	18 10
Porto Ferraio, Piombino,	—— 16, ——	16 20
Fiumicino, .	—— 19, ——	17 45
Gorgona, .	—— 2, ——	19 0
Girgenti, . .	July 18, ——	17 30
Ischia, . .	June 16, 1798	18 22
Lagos Bay, . .	Oct. 25, 1788	18 0

Names of Places.	Year of Observation.	Magnetic Variation.
VI.—*Portugal, &c. continued.*		
Leghorn, . .	Oct. 20, 1731	9° 42′ W.
	1785	18 0
	1795	19 20
	July 8-11, 1818	19 20
Lissabon, . .	1811	22 45
Maritimo, . .	Aug. 6, 1807	19 40
Maritimo Island,	May 28, 1818	17 0
	July 16, 1818	18 0
Malaga Bay, . .	Dec. 1, 1788	19 50
Malta, . .	1612	11 0
Minorca, C. Mola, .	April 15, 1811	19 30
Palermo, C. Guals, .	1790	17 0
	1814	18 30
Ustica, . .	July 15, 1818	17 30
Vido Fort, Alessandro,	——	14 34
VII.—*Hungary and Turkey.*		
Constantinople, .	1797	12 33
Corfu, . . .	1818	14 34
Maudry Bay, .	1793	13 20
Imbro Island, Dard. .	Aug. 27, 1807	12 32
Trebizonde, . .	1797	8 14
VIII.—*Asia and neighbouring Islands.*		
Alceste Island, . .	July 21, 1816	2 3 W.
Basil's Bay, .	Sept. 4, 1816	2 0 W.
Bata Harbour, . .	April 15, 1803	1 23 W.
Bildih, . .	June 11, 1580	10 40 W.
Cheaton Bay, . .	Aug. 22, 1816	2 10 W.
Cape Comorin, .	Mar. 30, 1815	2 9 E.
Congo River, . .	July, 1816	25 58 W.
Pointe de Galle, Ceylon,	April 2, 1814	2 15 E.
Trincomalee, . .	Sept. 27, 1812	1 9 E.
Derbent, . .	October, 1580	11 0 W.
Hyderabad, . .	June 27, 1804	1 16 E.
Batavia, Java, .	July 29, 1814	0 17 E.
Sourabaya, .	October, 1793	2 31 W.
	Sept. 1824	0 10·4 W.
Lam-Get Island, .	June 16, 1816	0 9 W.
Macao, . .	April 21, 1792	1 12 E.
Madras, . .	1809	3 0 E.
Morebat Bay, . .	1781	6 40
Muscat-Cove, .	1785	6 0
Mocha, . .	1795	11 0

Table XI.—*Continued.*

Names of Places.	Year of Observation.	Magnetic Variation.
VIII.—*Asia, &c. continued.*		
Murray's Sound, .	Sept. 8, 1816	2° 0′ W.
Napikiang Roads, Port Melville, .	Oct. 8, 1816	0 52 W.
Pecho Mouth, . .	July 27, 1816	2 14 W.
Princes' Island, .	May 16, ——	20 7 W.
Sandy Island, . .	July 27, ——	2 14 W.
Achen, Sumatra, .	May 1, 1814	2 25 E.
IX.—*Africa and neighbouring Islands.*		
Alexandria, .	May 11, 1694	12 48 W.
	April 8, 1822	10 58
Alboran Island, .	Jan. 8, 1818	21 28½
Africa Islands, . .	1802	7 44
Ascension, . .	1816	15 30
	Jan. 1825	16 52
Akromar, . .	March, 1828	11 16
Ambucol, . .	April, ——	10 46
Fagel, Azores, . .	1814	28 30
Bareedy Harbour, .	1776	13 53
Bomba, . .	1821	14 55
Bourbon, St Denys,	Aug. 10, 1813	17 20
Canaries, . .		
Funchal, . .	1802	19 10
	1811	21 0
	1813	22 0
	1816	21 10
	Feb. 1829	21 32
	Mar. 24, 1819	19 10
	July 5, 1821	25 58
Santa Cruz Bay, Teneriffe,	1816	21 20
Orotava, . .	——	20 38
Santa Cruz, .	Feb. 16, 1819	18 58
	Aug. 29, 1822	21 0
Chagos (Diego Garcia)	1786	1 59
Eleven Islands, . .	——	2 19
Commorish Islands.		
Mayotta, .	1750	20 0
Cape Verd Islands.		
Porto Praya, .	1812	10 15
	Mar. 18, 1819	13 30
Bonavista, .	Apr. 8, 9, ——	14 2
Mayo, . .	April, 1819	13 9
Sal, . .	Feb. 26, 1819	14 5
Mauritius, (Gard. Pr.)	Aug. 1805	11 42½
	Mar. 15, 1813	16 40
	Oct. 1824	13 46

TABLE XI.—*Continued.*

Names of Places.	Year of Observation.	Magnetic Variation.
IX.—*Africa, &c. continued.*		
Cape of Good Hope,	1792	24° 30′ W.
Table Bay,	1818	28 0
Cape Town,	——	27 30
Goree,	1801	16 0
	1815	19 35
	Mar. 21, 1819	15 50
Gough's Island,	—— 4, 1782	0 0
	Dec. 1813	11 51
Kossics Bay,	1799	11 13
St Helena,	Apr. 1798	15 28
Jamestown,	1815	17 30
	1816	17 30
Jamestown,	Dec. 1824	19 34·5
Mozambique Harb.	1802	18 40
Madagascar.		
Majambo Bay,	Feb. 1808	16 25
Morvundava,	Aug. 1714	22 30
Augustin's Bay,	1798	23 30
	1804	24 0
Bembatooka Bay,	1802	17 30
Nareenda Bay,	——	15 50
Patta,	1751	16 17
Prince Wales Island,	1819	22 30
Recief Cape,	Aug. 1797	26 40
	1814	29 20
Rassalgate,	1810	5 20
Suez Harbour,	1777	12 6
Tristan d'Acunha,	Mar. 6, 1813	9 51 N.
Tripoli,	1816	16 60
	June, 1822	16 35
St Thomas' Island,	May 20, 1816	22 48
Quiloa Island,		17 22
X.—*America and neighbouring Islands.*		
Acapulco,	Apr. 29, 1791	7 44 E.
	1821	8 46 E.
Arica,	1713	8 0 E.
	1821	10 25 E.
Arauco,	——	18 22 E.
Ancon,	——	10 25 E.
Baffin's Three Isles,	July 12, 1818	80 44 W.
S. Blas California,	Apr. 12, 1791	7 28 E.
	1821	8 40 E.

Names of Places.	Year of Observation.	Magnetic Variation.
	X.—*America, &c. continued.*	
Brandon House,	1808	12° 12′ E.
Big Lake,	1807	8 0
Carlisle B. Barbadoes,		4 30 E.
Curaçoa,	July 18, 1704	6 40 E.
	May 24, 1814	4 0 E.
	Mar. 10, 1818	2 1 E.
	1787	7 0 E.
Cayman,	1815	6 45 E.
Callao Castle,	1821	10 3 E.
Carthagena,	Nov. 1735	8 0 E.
	Jan. 1787	11 0
	May 1813	6 32
Point Coles,	1821	10 18 E.
Charlton House,	1807	15 16 E.
Chepewyan Fort,		16 0 E.
Havanna, Cuba,	1815	7 0 E.
	Aug. 1816	5 30
Caripe,	Sept. 20, 1799	3 15
S. Carlos de Chiloe,	Feb. 8, 1790	17 30 E.
Conception,	Nov. 21, 1791	14 52 E.
Coquimbo,	1712	10 0 E.
	Apr. 28, 1791	11 46
	1821	14 0
Callao de Lima,	1713	10 0 E.
	June 7, 1791	9 37½
	Mar. 3, 1823	9 30
S. Catharina,	Oct. 1822	6 25 E.
Churchill Fort,	1807	5 39 E.
S. Croix Island,	July 14, 1826	1 15 E.
Dominica,	June 22, 1760	8 20 E.
Pr. Rupert Bay,	April 8, 1819	2 40 E.
Puerto Deseado,	Dec. 7, 1789	19 50 E.
Domingo.		
C. Francais,	1745	5 15 E.
Alta Vela,	Feb. 1818	5 21 E.
Port Egmont,	Dec. 19, 1790	22 34 E.
Erie Fort,	1817	1 42 E.
Sta. Fé de Bogota,		7 35 E.
Fernando Noronha,	May 1745	2 10 E.
Guayra,	Jan. 24, 1800	4 20 E.
	June 3, 1814	4 58

Names of Places.	Year of Observation.	Magnetic Variation.
	X—America, &c. continued.	
Guayaquil, .	Oct. 11, 1791	9° 11′ E.
	1821	9 5
Guadaloupe, .	1809	4 55 E.
Guasco, . .	1821	13 30 E.
Hare Island, .	June 1818	71 58 W.
Juan Fernandez,	1744	8 30 E.
	1802	14 0
Jamaica, P. Royal	Nov. 1789	6 30 E.
	1817	4 40
Lima, . .	Dec. 1740	9 2 E.
	1802	9 50
Mexico, . .	Dec. 1803	8 8 E.
Mobile Bay, .	—— 1814	6 30 E.
Martinique, . .	1735	6 0 E.
F. Royal, . .	1816	6 45
Santa Martha, .	1743	6 35 E.
Mas-a-Fuera, .	1802	13 0 E.
Mohawk Bay, .	1815	0 4 E.
Port Mulgrave, .	July 1, 1791	26 40 E.
Le Maire Str. .	1712	24 0 E.
Mollendo, .	1821	11 5 E.
Mocha Island, .	1821	19 34 E.
Monto Video, .	Sept. 23, 1789	18 40 E.
	Aug. 1807	13 20
Monterras, . .	Sept. 28, 1791	10 56 E.
Niagara Fort, .	1817	1 27 E.
Nuacho, . .	1821	9 36 E.
Nootka, . .	Aug. 17, 1791	22 30 E.
Panama, . .	Nov. 1775	7 49 E.
	Dec. 3, 1791	7 49
	1802	8 0
	1821	7 0
Payta, . .	1821	9 0 E.
	March 8, 1823	8 56 E.
S. Pescadores, .	1821	11 25 E.
Porto Bello, .	Nov. 1735	8 40 E.
	1814	8 30
	1815	6 0
Prince of Wales' Fort,	1798	1 0 E.
	1807	5 39
	Sept. 3, 1813	6 0

Table XI.—*Continued.*

Names of Places.	Year of Observation.	Magnetic Variation.
X.—America, &c. continued.		
Pernambuco,	1815	8° 0′ w.
Penedo S. Pietro,	1813	6 0 w.
La Plata,	1743	8 30 E.
Cuito,	Feb. 1802	9 24 E.
Realeyo,	Jan. 28, 1791	9 20 E.
Rio Janeiro,	1821	3 21 E.
Talcahuana,	Nov. 21, 1793	14 52 E.
	1821	15 30
Fort Galvez,	Feb. 1823	16 16·4
St Thomas' Island,	1816	2 24 E.
Vera Cruz,	Mar. 15, 1769	6 28 E.
	1815	10 37
	April 27, 1819	9 16
Valparaiso,	Mar. 11, 1709	9 30 E.
	1744	12 30
	Mar. 20, 1709	13 39
	1795	14 49
	1802	14 55
	1821	14 43
Valdivia,	1788	17 30 E.
St Vincent's Island,	Mar. 31, 1814	7 30 E.
William's Fort,	Dec. 8, 1816	5 30 E.
Wollaston's Lake,	1807	18 2 E.
Ylo,	1802	10 30 E.
York Fort,	1807	4 55 E.
	Sept. 1819	6 0·3 E.
XI.—Australia.		
Amboyna,	Oct. 1823	0 28 E.
Bouroa, Cayeli,	Sept. 29, 1823	8 31·8 E.
Ceram, Selema Bay,	July 1796	8 41 E.
Dory Harbour, N. G.	—— 1824	1 35·6 E.
Galapagos Island,	1821	8 20 E.
Guaxon, Marian Isl.	Feb. 22, 1792	3 16 E.
Jervis Bay,	1800	9 0 E.
King's I. Elephant B.	1802	3 30 E.
Manilla,	July 18, 1792	0 17½ E.
[illegible] Port, N. Zeal.	April 1824	13 21·6 E.
N. Caledonia.		
Port St Vincent,	1803	10 [illegible] E.
Oyster Bay, New Hol.	1789	6 40 E.
Otaheite Point,	May [illegible]	6 40·4 E.
Offak,	Sept. 1823	1 1·7 E.

TABLE XI.—*Continued.*

Names of Places.	Year of Observation.	Magnetic Variation.
	XI.—Australia Continued.	
Port Praslin,	Aug. 1823	6° 40′·4 E.
Pulo Leah,	Mar. 1, 1816	0 52½ W.
Pulo Penang,	1787	0 11 W.
Port Cornwallis,	1809	1 57 E.
Port Philip,	1802	8 0 E.
Port Jackson,	Mar. 18, 1793	8 46 E.
	Jan. Feb. 1824	8 56
Paramatta,	Oct. 23, 1822	8 43·8 E.
	Feb. 10, 1813	0 46·8
	Mar. 26, ——	0 47·5
	Mar. 27, 1813	8 50.5
	—— 31, ——	0 43·5
Halan,		
Havre de la Coquille,	June 1823	9 20·5 E.

On the progressive Changes in the Variation of the Needle.

We have already seen that the variation of the needle experiences a progressive change in every part of the globe. The following table shews very satisfactorily the change which has taken place in London.

Table of the Variation at London from 1576 *to* 1831.

Years.	Observers.	Variations.	
1576	Norman	11° 15′	easterly.
1580	Burroughs	11 17	maximum.
1622	Gunter	6 12	
1634	Gellibrand	4 5	
1657 } 1662 }		0 0	no variation.
1666		0 34	westerly.
1670		2 6	
1672		2 30	
1700		9 40	
1720		13 0	

Years.	Observers.	Variations.			
1740		16°	10′		westerly.
1760		19	30		
1774		22	20		
1778	*Phil. Trans.*	22	11		
1790		23	39		
1800		24	36		
1806	*Phil. Trans.*	24	8		
1813	*Col. Beaufoy.*	24	20	17″	
1815	Ditto	24	27	18	maximum.
1816		24	17	9	
1820		24	11	7	
1823		24	9	40	
1831		24	0	0	

The following table shews the progressive change in the variation of the needle at Paris.

Table of the Variation at Paris from 1541 *to* 1829.

Years.	Variations.			Years.	Variations.		
1541	7°	0′	easterly.	1683	3°	50′	westerly.
1550	8	0		1700	7	40	
1580	11	30	maximum.	1750	17	15	
1603	8	45		1767	19	16	
1618	8	0		1780	20	35	
1630	4	30		1785	22	0	
1640	3	0		1800	22	12	
1659	2	0		1807	22	34	
1664	0	40		1814	22	54	
1669	0	0	no variation.	1819	22	29	
1667	0	15	westerly.	1824	22	23	
1670	1	30		1829	22	12·5	
1680	2	40					Arago.

The following table shews the progressive change in the variation in the southern hemisphere since the time of Vasco de Gama.

Table of the Variation at the Cape of Good Hope.

Years.	Variations.	Years.	Variations.
1605	0° 30′ easterly.	1724	16° 27′ westerly.
1609	0 12 westerly.	1752	19 0
1614	1 30	1768	19 30
1667	7 15	1775	21 14
1675	8 30	1791	25 40 maximum,
1702	12 50	1804	25 4

Professor Hansteen has explained these progressive changes in the variation of the needle by the motion of the four magnetic poles. Taking the variations at Paris for the northern hemisphere, he remarks that in 1580 the weak north pole in Siberia was about 40° east of Greenwich, or to the north of the White Sea, while the strong American pole was about 136° west of Greenwich, or 36° east of Behring's Straits. The west pole, therefore, lay *nearer* Europe than now, and the strong one *more remote*. Hence the action of the former predominated, and drew the needle eastward. But the *weak* pole now withdrew itself towards the Siberian Ocean from Europe, and the *strong one* approached it. The action of the latter therefore predominated, and the needle turned westward till 1814, when it reached its greatest declination and commenced its easterly course.

The explanation is equally satisfactory in reference to the southern hemisphere, and the variation at the Cape. In 1605 the *weak* south pole was 76½° west of Greenwich, and the *strong* south pole about 150° east of that meridian. The weak pole was, therefore, much *nearer* the Cape than now, while the stronger pole was *more remote* from it. The influence of the *weak* pole was therefore most powerful, so that the south pole of the needle moved towards the west, and its north pole more towards the east. But

when the *weak* south pole receded from the Cape, and the *strong* one approached it, the south pole of the needle turned more and more towards the strong pole, and its declination became consequently more westerly.

Mr Barlow has therefore given the following rule for calculating the variation of the needle, on the supposition that the magnetic pole which governs the needle in London was in 1818 in north latitude 75° 2′, and west longitude 67° 41′, and that its motion was uniform at the rate of 4° 14′ in *ten* years, the variation being 0°, or the pole being in the meridian of London, in 1660.

RULE. To the co-tangent of half the angle π N L (see the last figure) add the constant log. 1·65642; find the angle of which the sum is the tangent, and call it arc (A.) To the same co-tangent add the log. 0·03987, and find the arc of which the sum is the tangent, and call it arc (B.)

Then B — A will be the variation, or the angle π L N. The following comparison of the variations thus computed with actual observation is very interesting.

Years.	Variations. Observed.	Variations. Computed.	Differences.		Observers.
1660	0° 0′	0° 0′	0° 0′		Bond.
1670	2 30	2 44	0 14	+	Halley.
1690	6 0	7 59	1 59	+	Ditto.
1720	14 17	14 47	0 30	+	Graham.
1740	17 0	18 20	1 20	+	Ditto.
1750	17 48	19 47	1 59	+	Ditto.
1770	21 9	22 4	0 55	+	Heberden.
1780	23 17	22 54	0 23	—	Gilpin.
1790	23 39	23 33	0 6	—	Ditto.
1800	24 3	24 1	0 2	—	Ditto.
1810	24 11	24 18	0 7	+	Ditto.
1818	14 30	24 30	0 0		
1828		24 29			
1833		24 26			

The numbers in the column of differences are very small, and may rise as much from errors of observation as from a defect in the theory. The average difference is only about 45′.

Mr Barlow has computed the variation also for Paris and Copenhagen, and compared it with the best observations made at these places. The average difference for Paris is less than 30′. At Copenhagen it is 37′, or only 20′ if we throw aside the observed variation for 1731, which seems to err greatly in defect.

On the Annual Variation of the Needle.

Besides the progressive changes in the declination of the needle, M. Cassini observed an *annual* change depending on the position of the sun in reference to the equinoctial and solstitial points.

Between the months of *January* and *April* the magnetic needle recedes from the north pole of the globe, so that its western declination increases.

From *April* to the beginning of *July*, that is, from the vernal equinox to the summer solstice, the declination diminishes, or the needle approaches the north pole of the globe.

From the summer solstice to the vernal equinox, the needle, receding from the north pole, returns to the west, so that in October it has nearly the same position as in May, and between October and March the western motion is smaller than in the three preceding months.

Hence it follows, that during the *three* months between the vernal equinox and the summer solstice, the needle retrogrades towards the east; and during the following *nine* months its general motion is towards the west.

This important subject has particularly occupied the attention of M. Arago. Taking the mean declination of each day, or that of the maximum and minimum, and the

mean declination of each month, he has arranged in tables the mean monthly declinations at Paris from 1784 to 1788, and also those at London, near the equinoxes and solstices, from 1793 to 1805, as calculated from the observations of Mr Gilpin, and by a comparison of the results, he finds a maximum of declination towards the vernal equinox, and a minimum towards the summer solstice; but this difference was less at London than at Paris.

In comparing the observations of Cassini in 1786 with those of 1800, corresponding to the measures of Gilpin, M. Arago has found that they do not differ from one another in their magnetical relations, but in one point. In 1786 the annual change of declination was nine minutes, whereas in 1800 it was scarcely a minute. Hence, says he, it is worthy of remark, that the retrograde motion which the needle experiences between the vernal equinox and the summer solstice decreases at the same time with the general and annual motion towards the west.

At Salem in Massachusetts, where observations were made in 1810 by M. Bowditch, the declination is west, and has diminished for a great number of years about two minutes annually. In examining these observations, M. Arago does not find any trace of the period of Cassini. The declination has never diminished between the vernal equinox and the summer solstice, but it gradually increases from April to August. This increase is compensated by a decrease of the declination between September and December, so that the period seems to be transferred from spring to autumn. If this idea shall be found correct, M. Arago conceives that the annual changes will be regulated by the following principles.

1. When the needle, having a westerly declination, recedes from the meridian, it experiences a retrograde motion, which brings it back to this place. This is the discovery of Cassini.

2. This retrograde oscillation is greater in proportion as the annual change of declination is greater,—a result deducible from a comparison of Cassini and Gilpin's observations.

3. The oscillation disappears, and every month gives nearly the same mean declination, when, the needle having arrived at the limit of its western digression, the annual change of declination becomes nothing. This result is deducible from Colonel Beaufoy's observations.

4. When the westerly declination diminishes from year to year, no remarkable oscillations are observed in the needle towards the east, excepting between the months of September and December. This is the observation of Mr Bowditch. According to Colonel Beaufoy's observations, the daily variation is greatest in *June* and *August*, and less in July, so that the annual curve has two *maxima* and two *minima* in the course of the year, the two maxima being in June and August, and the two minima in December and July.

On the Diurnal Variations of the Needle.

That there is a daily change in the variation of the needle, as originally discovered by Mr Graham in 1724, has been placed beyond a doubt by observations made with the most accurate instruments in almost every part of the world. The following table contains the mean diurnal changes in the variation, according to the observations of Canton in 1759, of Gilpin in 1787 and 1793, and of Colonel Beaufoy in 1817–19.

Table of the Mean Daily Changes in Variation.

Months.	Observations of Canton. 1759.	Observations of Gilpin.		Colonel Beaufoy. 1817,18,19.
		1787.	1793.	
January,	7′ 8″	10′ 2″	4′ 3″	5′ 3″
February,	8 58	10 4	4 6	6 3
March, .	11 17	15 0	8 5	8 22
April, . .	12 26	17 4	11 7	11 48
May, . .	13 0	18 9	10 4	9 53
June, . .	13 21	19 6	12 6	11 15
July, . .	13 14	19 6	12 5	10 43
August, .	12 19	19 4	12 1	11 26
September,	11 43	15 5	9 8	9 44
October, .	10 36	14 3	7 0	8 46
November,	8 9	11 1	3 8	7 10
December,	6 58	8 3	3 8	4 7
Mean daily change,	10 43	14 39	8 0	9 32

The following Table shews the Amount of the Daily Variation at other Places compared with that at London.

London, general mean.	60′	44″	
Geneva.	15·	42	Saussure.
Chamouni.	17	6	Saussure.
Col du Geant.	15	43	Saussure.
Freiberg.	12	11·9	
Petersburg.	12	10·1	
Nicolajef.	10	53·4	
Kasan,	70	36·5	

When the diurnal variation of the needle was first discovered, it was supposed to have only two changes in its movements during the day. About seven A. M. its north end began to deviate to the west, and about two

P. M. it reached its maximum westerly deviation. It then returned to the eastward to its first position, and remained stationary till it again resumed its westerly course in the following morning. When magnetic observations became more accurate, it was found that the diurnal movement commences much earlier than seven A. M. but its motion is to the east. At half past seven A. M. it reaches its greatest easterly deviation, and then begins its movement to the west till two P. M. It then returns to the eastward till the evening, when it has again a slight westerly motion; and in the course of the night, or early in the morning, it reaches the point from which it set out twenty-four hours before. The most accurate observations made in England were those of Colonel Beaufoy, when the variation was about 24½ west. In these the absolute maxima were earlier than in Canton's observations, and the second maxima west about eleven P. M.

The following were the diurnal changes observed at Paris. During the night it is nearly stationary. At sunrise its north extremity moves to the westward, as if it were avoiding the solar influence. Towards noon, or more generally from noon to three o'clock, it attains its maximum westerly deviation, and then it returns eastward till nine, ten, or eleven o'clock in the evening; and then, having reached its original position, it remains stationary during the night. The amount of this daily variation is, for April, May, June, July, August, and September from 13′ to 15′, and for the other six months of the year from 8′ to 10′. On some days it rises to 25′ and on others it does not exceed 5′ or 6′.

According to M. Dove, the maximum easterly deviation of the needle takes place at eight A. M. at Freiberg, Nicolajef, and St Petersburg, and at nine A. M. at Kasan; and the maximum of westerly deviation at two P. M. at Kasan, Nicolajef, and St Petersburg, and at one P. M. at Freiberg.

In the northern regions, such as Denmark, Iceland, and Greenland, the diurnal variations are greater, and less regular. The needle is not stationary during the night, and it does not reach its maximum westerly deviation till between eight and ten P. M., and its most easterly about nine or ten A. M.

In advancing from the north to the magnetic equator, the diurnal variation diminishes in amplitude, and it ceases to be perceptible in the magnetic equator. Captain Duperrey, however, has found, that when the place is either under the magnetic equator, or at a little distance from it, the north point of the needle advances every morning to the *west* or to the *east*, according as the sun passes to the *north* or to the *south* of the place of observation.

In the southern magnetic hemisphere the daily variation takes place in an opposite manner, the *north* end of the needle moving to the east at the same hours that it did to the west in the northern hemisphere; a result which has been established by the observations of Mr J Macdonald at St Helena, and at Fort Marlborough in Sumatra.* M. Freycinet was led to the same result by observations made in the Isle of France, Timor, Rawak, Guham, Mowi, Port Jackson, and other places. At the Marianne and Sandwich Isles, in the northern hemisphere, the *north* point of the needle moves to the west, as in Europe, from eight A. M. till one P. M. though the variation there is easterly. At Timor, Rawak, and Port Jackson, to the south of the equator, the north point of the needle moves during the morning in an opposite direction; hence the observations made to the north of the line agree with those in Europe, while those in the southern hemisphere, like those of Macdonald, exhibit

* Made in 1794, 1795, and 1796; see *Philosophical Transactions*. Mr Macdonald observes, that the diurnal variations are sensibly less between the tropics than in Europe.

an opposite motion. M. Freycinet found that the diurnal oscillations have a small amplitude between the tropics. At Rawak, only the fortieth of a degree south of the equinoctial line, M. Freycinet found that the needle oscillated every day with an amplitude of 3′; so that it is the magnetic, and not the terrestrial equator, as Duperrey afterwards found, which separates the zone of westerly from the zone of easterly diurnal variations.

Observations are still wanting to shew whether or not the daily variations have the same direction in places where the variation is westerly and in those where it is easterly.

The dipping needle also undergoes, as will be afterwards seen, daily variations, but their amplitude is of less amount. There can be no doubt, as M. Pouillet observes, that a needle capable of moving in any given azimuth will experience daily changes; and that a needle moveable in every direction round its centre of gravity would describe every day a cone whose base would be an ellipse, or some other curve more or less elongated, in different parts of the earth.

The sun is now universally allowed to be the cause of the diurnal variations of the needle. Canton ascribed them to the action of solar heat, having ascertained that heat tends to diminish the attractive powers of a magnet, and assuming that the direction of the needle was due to the resultant of all the magnetic forces of the terrestrial sphere. When the sun was to the eastward of the needle, the forces lying to the eastward suffered a diminution of power, in consequence of which the westerly force prevailed, and the north end deviated to the west. When the sun, on the other hand, was to the westward of the needle, the power on that side diminished, and the needle returned again to the eastward. Canton, however, did not give any explanation of the morning easterly variation of the needle.

On the Irregular Motions of the Magnetic Needle as produced chiefly by the Aurora Borealis.

Besides the regular changes of an annual and diurnal nature to which the needle is subject, it is sometimes affected with sudden and extraordinary movements, to which Baron Humboldt has given the name of *magnetic hurricanes*, during which the needle traverses with a shivering motion, and often oscillates several degrees on each side of its mean position.

These sudden and capricious motions have been most frequently observed during the existence of the *auroræ boreales*, and have therefore been ascribed to that cause. The influence of this meteor on the magnetic needle was first noticed by Wargentin in 1750. It was observed by Bergman and others; and Van Swinden remarks, that he seldom failed to observe auroræ boreales after any anomalous motion of the needle; and he always concluded that there must have been one at the time, though he did not see it. As needles made of other substances, such as copper or wood, have not been found to be affected, the action of the aurora cannot be considered as an electrical one.

The influence of the aurora on the needle has been particularly studied by Dr Dalton, who has stated his views in his *Meteorological Observations and Essays*, published in 1793, in a dissertation of great ability, which has never received the notice which it merits. He has shown that the luminous beams of the aurora are parallel to the dipping needle; that the rainbow-like arches cross the magnetic meridian at right angles; that the broad arch of the horizontal light is bisected by the magnetic meridian; that the boundary of a limited aurora is half the circumference of a great circle crossing the

magnetic meridian at right angles, the beams perpendicular to the horizon being only those on the magnetic meridian.

Dr Dalton has shown, from numerous observations, that the aurora exercises an irregular action on the magnetic needle; and he has deduced from these observations the following results.

1. When the aurora appears to rise only about 5°, 10°, or 15° above the horizon, the disturbance of the needle is very little and often insensible.

2. When it rises up to the zenith, and passes it, there never fails to be a considerable disturbance.

3. This disturbance consists in an irregular oscillation of the horizontal needle, sometimes to the eastward and then to the westward of the mean daily position, in such sort that the greatest excursions on each side are nearly equal, and amount to about half a degree each at Kendal.

4. When the aurora ceases, or soon after, the needle returns to its former station.

Professor Hansteen's observations on the magnetical influence of the aurora are peculiarly interesting. He states, that the extraordinary shivering movements of the needle are perhaps never exhibited except when the aurora is visible; and that this disturbance seems to operate at the same time in places the most widely separated. The extent of these movements may in less than twenty-four hours amount to five or five and a half degrees. In such cases, he adds, the disturbance is also communicated to the dipping needle; *and as soon as the crown of the aurora quits the usual place, (the points where the dipping needle produced would meet the sky,) that instrument moves several degrees forward*, and seems to follow it. After such disorders, he continues, the mean variation of the needle is wont to change, and not to recover its previous magnitude till after a new and similar disturbance. During the continuance of the aurora borealis,

the intensity of the earth's magnetic force seems to grow weaker; for which reason the needle recedes from that magnetic pole where the ray of the aurora is displayed.

The influence of the aurora borealis on the needle has been studied with particular care by M. Arago, whose accurate and regularly continued series of observations on the daily changes of the magnetic needle at Paris has enabled him to compare these changes with the occurrence of the northern light. The following is an abstract of his views on the subject: The appearance of an aurora causes the magnetic needle to vary several degrees to the east and west of its mean position. In the region where it appears, luminous beams, differently coloured, shoot up from all points of the horizon; *and the part of the heavens where all these beams or radiations unite is precisely that to which a magnetic needle directs itself when suspended by its centre of gravity.* M. Arago has also shewn that the concentric circles, which shew themselves almost always before the luminous beams, rest each upon the two points of the horizon equally distant from the magnetic meridian, *and that the most elevated points of each arch are exactly in this meridian.* From these two facts he concludes that there is a relation between the causes of the aurora borealis and the motions of the magnetic needle; and, from observations made in places remote from each other, he infers that the aurora acts even before it shews itself in the horizon, and that its influence is exerted at very considerable distances. In a subsequent paper on the subject, M. Arago shews that the auroras which are visible only in America, at St Petersburg, and in Siberia, in spite of the immense distance which separates us from these regions, produces a perceptible derangement of the magnetic needle at Paris. M. Arago at first believed that even the auroras of the southern hemisphere extended their influence to Paris; but he has since found, that on the days when these southern

auroræ took place, the phenomenon was observed also in the north, so that no conclusion can be properly deduced from this coincidence with the observed derangements of the needle.

M. Kupffer has confirmed by his own observations the first results obtained by M. Arago, and is of opinion that the aurora extends its influence to a great distance. When the needle was driven from its mean position by the influence of this meteor, M. Kupffer could not perceive any sensible difference between the duration of an oscillation at this time and at any other. He has, however, excepted some cases where the deviation was very considerable; but what was very remarkable was, that when the needle deviated to the east, the duration of an oscillation was greater than usual, whilst on the 24th November, 1825, when the needle deviated to the west, the duration of an oscillation was smaller. On the other hand, the dip being in the ratio of the duration of the oscillation, the preceding observations seem to prove that the dip diminishes when the needle deviates to the west, and increases with an easterly deviation.

Notwithstanding the body of evidence which proves the connection between the aurora and the derangement of the needle, it is a very remarkable fact that during the frequent occurrence of that meteor at Port Bowen, Captain Foster did not observe any peculiar changes in the deviation of the needle, although, from his vicinity to the magnetic pole, the diurnal variation sometimes amounted to 4° or 5°, and it was to be presumed that the slightest action of the aurora would, under such circumstances, have been visible. From these observations of Captain Foster and others, the natural conclusion is, that there are some auroræ which do not disturb, while there are others which do disturb, the magnetic needle.

During Captain Back's residence at Fort Reliance (north latitude 62° 46′ 29″, and west longitude 109° 0′

39″) for *six* months in 1833-4, and *four* months in 1834-5, the aurora occurred almost every night. The magnetic needle seems to have been constantly affected by it, and on one occasion the effect exceeded *eight degrees*. "Brilliant and active coruscations of the aurora borealis," says Captain Back, "when seen through a hazy atmosphere, and exhibiting the prismatic colours, almost invariably affected the needle. On the contrary, a very bright aurora, though attended by motion, and even tinged with a dullish red and a yellow, in a clear blue sky, seldom produced any sensible change, beyond, at the most, a tremulous motion.

"A dense haze or fog, in conjunction with an active aurora, seemed uniformly favourable to the disturbance of the needle; and a low temperature was favourable to brilliant and active coruscations. On no occasion, during two winters, was any sound heard to accompany the motions. The aurora was frequently seen at twilight, and as often to the eastward as to the westward. Clouds, also, were often perceived in the day time, in form and disposition very much resembling the aurora."

Mr Christie has explained the absence of any apparent action of the aurora, by the supposition that the apparatus employed was not fitted to exhibit that action; and he entertains therefore the opinion, "that changes in the deviation and intensity of the terrestrial forces are simultaneous with the aurora borealis." The following is the method recommended by Mr Christie for observing the effects of the aurora to the greatest advantage.

"If the magnetic forces brought into action during an aurora are in the direction of the magnetic meridian, they will affect a dipping needle adjusted to the plane of that meridian; but the direction of an horizontal needle will remain unchanged. On the other hand, if the resultant of these forces makes an angle with the meridian, the

direction of the horizontal needle will be changed, but the dipping needle may not be affected. In order to determine correctly the negative influence of the aurora, by means of an horizontal needle, it is therefore necessary not only to have regard to those forces which influence its direction, but likewise to those which affect the horizontal intensity. The effects of the former are the objects of direct observation, but those of the latter are not so immediately observable. As, during an aurora, the intensity may vary at every instant, and it is these changes which are to be detected, the method of determining the intensity by the time of vibration of the needle cannot here be applied, and other means must be adopted. The best method appears to me to be that which I employed for determining the diurnal variation of the horizontal intensity, the needle being retained nearly at right angles to the meridian by the repulsive force of a magnet, or by the torsion of a fine wire or thread of glass. For the purpose, then, *of detecting in all cases the magnetic influence of the aurora*, I consider that two horizontal needles should be employed; one adjusted in the meridian, for determining the changes which may take place in the direction of the horizontal force, and the other at right angles to the meridian, to determine the changes in the intensity of that force, arising principally from new forces in the plane of the meridian, and which would affect the direction of the dipping needle alone. Both these needles should be delicately suspended, either by very fine wire, or by untwisted fibres of silk. In order to render the changes in the direction of the needle in the meridian more sensible, its directive force should be diminished by means of two magnets north and south of it, and having their axes in the meridian. These magnets should be made to approach the needle, until it points about 80° on either side of the meridian, and they should be so adjusted that the forces acting upon the needle will retain it *in equilibrio*, with its marked end at about 80°

to the east and 30° to the west of north, and also at south. The needle is to be left with its marked end pointing south, for the purpose of observing the changes occurring in its direction. If magnets are employed to retain the second needle nearly at right angles to the meridian, they should be made to approach its centre until the points of equilibrium are about 80° east, 80° west and south, the observations being made with the needle at 80° east and 80° west. An objection to this method of adjusting this needle by means of magnets is, that any change in their temperature will have a very sensible effect on the direction of the needle in this position; and should such change take place during the observations, corrections must be applied to the results before any accurate conclusions can be drawn from them. I have before remarked, that this inconvenience will be in a great measure obviated by employing the torsion of a fine wire, or a very fine plummet of glass to retain the needle at about 80° from the meridian. In this case, the ratio of the force of torsion to the terrestrial force acting upon the needle having been determined, a measure will be obtained of the changes which take place in the intensity of the terrestrial force during the occurrence of an aurora. It is very desirable that it should be ascertained whether the effects on the needle are simultaneous with any particular class of phenomena connected with the aurora; whether these effects are dependent on the production of beams or coruscations, or on the formation of luminous arches; or whether any difference exists in the effects produced by them. In order to determine this, it is necessary that the times of the occurrence of the different phenomena, and also of the changes in the directions of the needles, should be accurately noted; and for such observations three observers appear to be indispensable."

It has become a question of some importance, whether the electric state of the clouds produces any effects upon the needle; and this question has increased in interest

since the discovery of the magnetical effects of galvanic and common electricity. Mr Christie has made some valuable observations on this subject. Adjusting in a particular manner a needle between two magnets, so that its directive force was considerably diminished, he found that changes in the position of electric clouds were accompanied by changes in the position of the needle. Captain Sir Everard Home also observed, that, in two instances, a vibrating needle came sooner to rest during a thunder-storm than it did either before or after it. The number of vibrations was reduced in one case from 100 to 40, and in another from 200 to 120.

An analogous fact was observed by Captain Back, in 1833, at Fort Alexander, at the southern extremity of Lake Winnipeg, where a "considerable alteration appeared, both in the number of vibrations, and the point at which the needle finally rested. A second time shewed a similar discrepancy. The reason of this peculiarity I could not divine, until about an hour afterwards, when some gentlemen arrived from the westward, and acquainted us that they had just encountered a severe thunder shower, though the sky over the fort underwent no visible change, and wore the same sultry aspect as it had done most of the forenoon."*

The view which we have given, in a subsequent section, of the magnetic conditon of our atmosphere, arising from the uniform dissemination of ferruginous and other metallic matter, enables us to give a satisfactory explanation of the general phenomena of the aurora, of its action on the needle, and of the circumstances under which it will affect or not affect its stability. That there is magnetic matter in the atmosphere is indubitable, and that this matter may be heated by the electricity of the atmosphere, so as to give out light of different colours, and may have its magnetic influence increased or diminished by this electrical action, as well as by ordinary changes

* *Narrative of the Arctic Land Expedition, &c.* p. 41, 42.

of temperature, cannot be doubted. When the magnetic forces are in a state of equilibrium, the needle will take its mean position, subject only to those diurnal changes which arise from the action of solar heat. But when the magnetic matter is exposed to the electrical agents which exercise so powerful an influence on the regions of the clouds, when the ferruginous matter, and the other metallic vapours which accompany it, are rendered luminous by the transmission of the electric fluid, and when the magnetic matter has its induced magnetism either diminished or increased by this cause, the resultant of the forces which act upon the needle must be changed, and motions regular and irregular, easterly and westerly, or in any given direction, communicated to a needle freely suspended by its centre of gravity. A local displacement of the magnetic matter, by the various causes which are constantly disturbing our atmosphere, or local and limited electric action, must necessarily affect such a needle; but it is easy to conceive that those local and limited actions may be such as to balance each other, and not change the direction of the resultant force which acts either upon a horizontal or a dipping needle. Nay, it is easy to conceive a general diffusion of electricity, capable of illuminating the magnetic matter with such perfect equality in all magnetic azimuths, without at all affecting any needle, however balanced or suspended; because the electrical influence may not change the direction of the resulting forces which give the needle its mean direction. In such a case, however, it is probable that the magnetic intensity might be increased or diminished during the existence of such an electric state of the magnetic matter. We cannot, therefore, adopt the opinion of Mr Christie, *that every aurora must disturb the magnetic needle*; and we admit only the observed fact, that there are auroras which disturb, and auroras which do not disturb, the needle.

In order to explain more fully our views on this sub-

ject, let us suppose our magnetic atmosphere to be undisturbed by any cause, and that the needle in every magnetic meridian rests in a state of perfect equilibrium in its mean position. Let us now suppose that the magnetic atmosphere is disturbed in east longitude 90° and latitude 0°, either by a change of temperature, or by electric action, or by any cause which displaces the magnetic matter from that meridian, or accumulates it there. Such a change must necessarily affect the horizontal magnetic needle in all places to the east and west of it; but it will not affect the horizontal needle in the meridian where it takes place, or in the opposite meridian, as the resultant of the magnetic forces, though they may be changed in intensity, will not be changed in direction. In like manner, if various discharges take place simultaneously or successively, there will be certain places where the direction of the resultant forces is not changed, and other places where the change of direction is a maximum. An universally suspended needle, however, will have its direction always changed, unless when the disturbing cause is in the direction of its axis, or in a plane perpendicular to that axis. Hence, then, it is easy to understand (nay, the fact is a necessary result of our hypothesis) why there are auroras which disturb and auroras which do not disturb the needle, why distant auroras affect it when nearer ones do not, and why the needle is in a shivering or constantly oscillating state during auroras in which the places where the magnetic atmosphere is disturbed are constantly changing. In the same manner, we may account for the influence on the needle, observed by Sir Everard Home and Captain Back, during the prevalence of a thunder-storm, while the electricity of the atmosphere destroys by its action the magnetic equilibrium, when this action is not compensated by an equal one on the opposite side of the magnetic meridian. When such a compensation takes place, the needle will not deviate from its mean position,

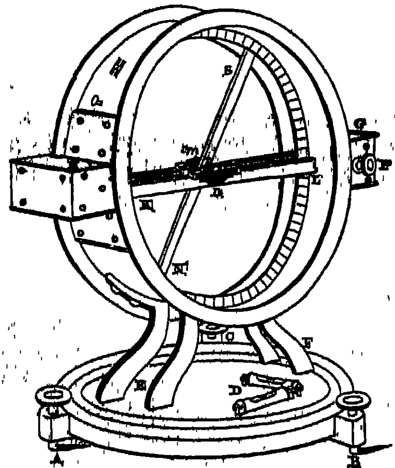
though the number of its vibrations in a given time may be altered.

Among the other causes which have a tendency to disturb the magnetic needle, we may enumerate earthquakes and volcanic eruptions, all of which are accompanied in general with electrical phenomena. In 1767, Daniel Bernoulli observed the dip of the needle to diminish half a degree during an earthquake; and De la Torre observed changes of several degrees in the variation of the needle during an eruption of Vesuvius.

SECT. II. — *On the Dip or Inclination of the Needle.*

The dip or the inclination of the needle is, as we have already had occasion to observe, the angle which a well-balanced needle forms with the horizon after it is rendered magnetic, and when it has the power of free motion in the plane of the magnetic meridian, as shewn in fig. 55,

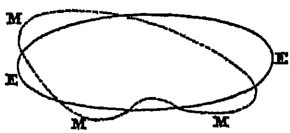
Fig. 55.



where NS is the needle balanced on a horizontal axis, at right angles to its length.

The dip of the needle, like the variation, has different values in different parts of the globe; generally speaking, being nothing, or horizontal, near the equator, and 90°, or perpendicular to the horizon, at the magnetic poles. The line passing round the globe near its equator, in every part of which the dip is nothing, is called the *magnetic equator*, which is a very irregular line, crossing the equator at *four* points, as shewn in the annexed figure, where the black line E E is the real equator, and the dotted line MMM the magnetic equator, which is seen to cross the other at four points, in place of two.

Fig. 56.



The general inclination of the magnetic to the terrestrial equator is about 12°, its principal intersections or nodes being placed in 113° 14′ west longitude and 66° 46′ east longitude from Greenwich; and it is a tolerably regular line throughout one half of its circumference in the Atlantic and Indian Oceans. In discussing the observations made by Cook and others in the South Sea, M. Biot has shewn that the above elements are incorrect every where beyond the western node, between 115° and 270° west longitude; and he concludes that between 256° and 158° 50′ of west longitude it again cuts the terrestrial equator at least once, which renders it necessary that it cut it another time near the east coast of Asia, provided it is found in the Atlantic Ocean or the south latitude. Hence there will be at least three nodes, and perhaps four, as shewn in the preceding figure. This singular inflexion of the magnetic equator in the South Sea has been confirmed by the more recent observations of M. Freycinet.

The exact position of these nodes, and the true form

of the magnetic equator, have been determined with great care by M. Morlet and M. Hansteen. There are some slight differences between their results, which have been pointed out by M. Arago, in the following excellent summary of the results of their inquiry. Both Morlet and Hansteen place the magnetic equator wholly to the south of the terrestrial equator, between Africa and America; its greatest southern latitude being at 25°, one node is in Africa, in about 22° of east longitude, or in 18° according to Morlet. In setting out towards the east from this node, which is nearly in the centre of that part of the African continent, the magnetic equator advances rapidly to the north of the terrestrial equator, quits Africa a little to the south of Cape Guardafui, and in the Arabian Sea it attains its most northerly latitude of about 12°, in 62° of east longitude. Between this meridian and 174° east, the magnetic equator is constantly to the north of the equinoctial line. It cuts the Indian peninsula a little to the north of Cape Comorin, traverses the Gulf of Bengal, making a slight advance to the equinoctial, from which it is only 8° distant at the entry of the Gulf of Siam. It then re-ascends a little to the north, almost touches the north point of Borneo, traverses the isle of Paragua, the strait which separates the most southern of the Philippines from the isle of Mindanao, and under the meridian of Naigiou it again reaches the north latitude of 9°. From this point it traverses the archipelago of the Caroline Islands, and descends rapidly to the equinoctial line, which it cuts, according to Morlet, in 174°, and according to Hansteen in 187°, of east longitude. There is much less uncertainty respecting the position of a second node, also situated in the Pacific Ocean. Its west longitude ought to be about 120°; but while M. Morlet's inquiries lead him to conclude that the magnetic equator merely touches the equinoctial at that point, and then bends again to the south, M. Hansteen makes it cross the line into the northern hemisphere,

and continue there through an extent of 15° of longitude, and then return southward, and cross the equinoctial again in about 108° of west longitude, or 23° from the west coast of America. This discrepancy between the deductions of Morlet and Hansteen is, after all, very trivial; for, in the case just mentioned, the magnetic equator does not go more than $1\frac{1}{2}$° to the north of the equinoctial; and, in general, the magnetic equator of Morlet differs in no part so much as 2° in latitude from that of Hansteen.

The magnetic equator thus traced over the globe has a motion from east to west, in so far as can be determined by direct observations on the position of its nodes. The two nodes of Hansteen, corresponding to the tangent node of Morlet, are divided between 108° and 126° of west longitude. In 1819, M. Freycinet found, on board the Uranie, that this node was in 132° of longitude; and Captain Sabine found that the node in Africa, which was far from the coast in 1780, had advanced from east to west even to the Atlantic Ocean. M. Morlet had indicated, with some distrust, this motion of the magnetic equator; and he considered it probable that its form and position regulated the direction of the annual variations of the needle. He found that the dip of the needle diminished wherever the motion of the equator tended to diminish the magnetic latitude, and that it increased, on the contrary, wherever the magnetic latitude was increased,—a result which was confirmed by future observations.

Much light has been thrown on the subject of terrestrial magnetism, but particularly on the form and motion of the magnetic equator, by the observations of Captain Duperrey, made on board the Coquille, in the years 1822–1825. This vessel crossed the magnetic equator six times, and M. Duperrey was able to determine directly two of its points, situated in the Atlantic Ocean.

On the chart of M. Morlet, and in that of Hansteen, the latitude of those parts which correspond to the same longitudes are greater by 1° 43′ and 1° 50′; and hence M. Arago has concluded that the magnetic equator has approached the terrestrial equator by the same quantities. In the South Sea, near the coast of America, M. Duperrey has determined two points of the magnetic equator. On the charts of Morlet and Hansteen the latitudes of these points are about a degree smaller, but the difference is in a direction contrary to that which was found in the Atlantic Ocean; from which it follows, that, near the coast of Peru, the magnetic equator has removed from the equinoctial line.

In discussing the magnetic observations made on board the Coquille, M. Duperrey has traced the form of the magnetic equator with an unexpected degree of accuracy; employing the formula of Barlow, which makes the tangent of the magnetic latitude equal to half the tangent of the dip, and making one only of dips which do not exceed 30°. Having obtained the magnetic latitudes of the places where the observations were made, he deduces, both from these and from the variation of the needle at the same place, the changes in longitude and latitude, which, being combined with the geographical positions of the stations, give him the co-ordinates of the corresponding points of the magnetic equator. By means of this method, and relying only on his own observations, he has traced a portion of this curve through an extent of 247° of longitude, comprehending the Atlantic Ocean, a part of South America, the great equinoctial Ocean, and the Asiatic archipelago, as far as the western extremity of the island of Borneo. In prolonging the magnetic equator to the east, he has used the observations of Captain Sabine in 1822, made in the island of St Thomas, in the Gulf of Guinea. Between the west of Borneo and the north of Ceylon, he availed himself of the obser-

vations made in 1827, by M. de Blosseville, in the Chevrette. Adopting Captain Sabine's determination of one of the nodes of the magnetic equator, which he places 3° 20′ to the east of the meridian of Paris, not far from the west coast of Africa, M. Duperrey shews that this equator, after resting at this node, rises to the north, traverses Africa, and reaches probably the fifteenth degree of north latitude, in the Red Sea (as appears from an observation made by Pantin in the isle of Socotra in 1776.) It then descends a little to the south, to join a point in it fixed by M. Blosseville in the north of Ceylon. From these facts it appears, *that the magnetic equator will meet the equinoctial line only in two points, which are diametrically opposite, the one situated in the Atlantic Ocean, and the other in the great ocean nearly in the plane of the meridian of Paris. When this equator meets only some scattered islands, it recedes only a little from the equinoctial line. When the islands are more numerous, it recedes farther; and it reaches its maximum deviation in both hemispheres only in the two great continents which it traverses. He found also, that between the northern and southern halves of the magnetic equator, there is a symmetry very remarkable, aud much more perfect than had been previously believed.* These results are laid down by M. Duperrey in a chart of the equatorial regions, published in the *Ann. de Chimie* for 1830.

The dip of the needle increases on each side of the magnetic equator, and Hansteen has projected the lines of equal dip in his chart already referred to. These lines are nearly parallel to the magnetic equator, till we reach 60° of north latitude, and they then begin to bend round the American magnetic pole, which Commander Ross found to be situated in north latitude 70° 5′ 17″, and west longitude 96° 45′ 48″, the needle having at this point, in Boothia Felix, lost wholly its directive

power, and the dip being 89° 59′, within a minute of 90°. Had we inferred the position of the needle from the form of the magnetic equator, we should have placed it in 25° of west longitude, namely, the meridian in which the magnetic equator advances farthest to the south, or about 13½°, and in 76½° of north latitude, or 90° — 13½°. This, however, as all the arctic observations prove, is not the case; and we are led by the phenomena of the dip, as well as by those of the variation in different points of the globe, to conclude that every place has its own magnetic axis, with its own pole and its own equator, as already stated by Mr Barlow.

The following table contains the best observations on the dip of the needle, as collected by Professor Hansteen;—

Places of Observation.	Dip.	Intensity.
	South.	
Port du Nord,	75° 50′	1·5773
Port du Sud,	70 48	1·6133
Surrobaya in Java,	25 40	0·9348
Amboyna,	20 37	0·9532
Lima,	9 59	1·0773
Magnetic Equator in Peru,	0 0	1·0000
	North.	
Tompenda,	3 11	1·0191
Loxa,	5 24	1·0095
Cuença,	8 48	1·0286
Quito,	13 22	1·0675
St Antonio,	14 25	1·0871
St Carlos,	20 47	1·0480
Popayan,	20 53	1·1170
Santa Fe de Bogota,	24 16	1·1473
Javita,	24 19	1·0675
Esmeralda,	25 58	1·0577
Carichana,	30 24	1·1575
St Thomas,	35 6	1·1070
Carthagena,	35 15	1·2938
Cumana,	39 47	1·1779
Mexico,	42 10	1·3155
Atlantic Sea, B. 20° 40′ n. L. 41° 26′ w. F.	41 46	1·1779

Places of Observation.	Dip.	Intensity.
Atlantic Sea,	North.	
B. 11° 0′ n. L. 44° 32′ w. F.	41 57	1·2617
— 12 34 — — 33 14 —	45 8	1·2300
— 14 20 — — 28 3 —	52 55	1·2880
— 20 8 — — 8 34 —	56 42	1·2510
— 21 36 — — 5 39 —	47 49	1·2617
— 25 15 — — 0 36 —	60 18	1·2830
Portici, ...	60 5	1·2883
Naples, ...	61 35	1·2745
Rome, ...	61 57	1·2642
Vesuv. Crater, . . .	62 0	1·1933
St Cruz, Teneriffe, . .	62 25	1·2723
Valencia, ...	63 38	1·2405
Florence, ...	63 51	1·2782
Atlantic Sea,		
32° 16′ n. 2° 52′ w. . .	64 21	1·2938
Barcelona, ...	64 37	1·3482
Marseilles, ...	65 10	1·2938
Nimes, ...	65 23	1·2938
Mailand, ...	65 40	1·3121
Montpellier, ...	65 53	1·3482
Airola, ...	65 55	1·3090
Turin, ...	66 3	1·3364
Medina del Campo, . .	66 9	1·2938
Lans le Bourg Mont Cenis, .	66 9	1·3227
Como, ...	66 12	1·3104
St Michel, ...	66 12	1·3488
Lyons, ...	66 14	1·3384
St Gothard, ...	66 22	1·3138
Mont Cenis, . . .	66 22	1·3441
Ursern, ...	66 42	1·3069
Altorf, ...	66 53	1·3228
Atlantic Sea,		
37° 14′ n. 8° 30′ . .	67 30	1·3155
38 52 – 8 40 . .	67 40	1·3155
Madrid, ...	67 41	1·3938
Tübingen, ...	68 4	1·3569
Atlantic Sea,		
38° 52′ n. 8° 40′ . .	68 11	1·3155
Ferrol, ...	68 32	1·2617
Paris, ...	69 12	1·3482
Göttingen, ...	69 29	1·3485
Berlin, ...	69 53	1·3703
Carolath, ...	68 21	1·3509
Berlin, ...	68 50	1·3533
Dantzig, ...	69 44	1·3787
London, ...	69 57	1·3697

Places of Observation.	Dip.	Intensity.
	North.	
Ystad,	70° 13′	1·3742
Schleswig,	70 36	1·3814
Copenhagen,	70 36	1·3672
Odensee,	70 50	1·3650
Helsinburg,	70 52	1·3782
Kolding,	70 53	1·3846
Soroe,	70 57	1·3842
Freidrichsburg,	70 59	1·4028
Aarhuus,	71 13	1·3838
Aalborg,	71 27	1·3660
Odensala,	71 39	1·3666
Friedrichshaven,	71 48	1·3842
Göttenburg,	71 58	1·3826
Altorp,	72 14	1·3891
Korset,	72 24	1·3735
Quistrum,	72 27	1·4070
Skieberg,	72 29	1·3725
Elleoen,	72 38	1·3340
Helgerone,	72 39	1·3980
Soner,	72 41	1·3835
Christiania,	72 34	1·4195
Ryenberg,	72 45	1·4208
Bogstad,	72 34	1·4378
Bogstadberg,	73 13	1·4195
Nasoden,	73 2	1·4517
Bärum,	72 44	1·3902
Bolkesjoe,	73 15	1·4053
Ingolfsland,	73 19	1·4159
Norsteboe,	73 33	1·4136
Drammon,	73 37	1·3771
Maursäter,	73 44	1·4656
Ullensvang,	73 44	1·4260
Gran,	73 45	1·4221
Köngsberg,	73 47	1·4144
Tomlevold,	73 50	1·4246
Bekkorvig,	73 58	1·4114
Vang,	73 59	1·4308
Bergen,	74 3	1·4220
Moé,	74 8	1·4254
Maurastuen,	74 4	1·4058
Leierdal,	74 6	1·4190
Slidre,	74 34	1·4548
Brasso,	74 21	1·4471
Davis Straits, 68° 22′ n. 36° 10′ w.	83 8½	1·6365
Hare Island, 70° 26′ n. 37° 12′ w.	82 49	1·6406

Places of Observation.	Dip.	Intensity.
Baffin's Bay,	North.	
75° 5′ n. 42° 43′ w. .	84° 25′	1·6169
75 51 – 45 26 — . .	84 44½	1·6410
76 45 – 58 20 — .	86 9	1·7052
76 0 – 60 41 — . .	86 0	1·6885
70 35 – 49 15 — .	84 39	1·6837
Magnetic Pole,		
70° 5′ 17″ n. 96° 45′ 48″ w.	89 59	

The following table contains a series of accurate observations on the dip of the needle, made in 1829, by Baron Humboldt, during his journey to the Uralian and Altaian Mountains, and the Caspian Sea. The dip in the table is the mean of two measures taken with two different needles.

Places.	Longitude East of Paris.	North Latitude.	Dip.	Time of Observation.
Berlin, ...	11° 3′ 30′	52° 31′ 13″	68° 30′·7	April 9
Konigsberg, ...	18 19 40	54 42 50	69 25 ·8	— 17
Sandking,.........	18 47 30	55 42 13	69 39 ·8	— 20
Petersburg, ...	27 59 30	59 56 31	71 6 ·7	Dec. 6
Moscow, ...	35 17 0	55 45 13	68 56 ·7	Nov. 6
Kasan, ...	46 47 30	55 47 51	68 26 ·7	May 10
Ekatherineburg,..	58 14 15	56 50 13	69 9 ·7	July 15
Beresowsk, ...	58 24 15	56 54 0	69 18 ·2	June 20
Nijne-Taghilks,...	57 56 15	57 55 0	69 29 ·8	— 30
Nijne-Tourinsk,..	57 55 13	58 41 0	70 58 ·7	July 2
Tobolsk, ...	65 45 0	58 11 43	70 55 ·6	— 23
Barnoul, ...	81 50 0	53 19 0	68 9 ·8	Aug. 4
Zmeinogorsk, ...	80 25 0	51 8 0	66 5 ·5	— 8
Ustkamenogorsk,	79 55 0	49 56 0	64 47 ·6	— 20
Omsk,.............	71 13 0	54 57 0	68 54 ·2	— 27
Petropawlowsk,..	66 48 0	54 52 0	68 18 ·4	— 30
Troitsk, ...	59 13 0	54 5 0	67 14 ·2	Sept. 5
Minsk, ...	57 44 0	54 58 0	67 40 ·2	— 6
Zlatoounst,........	57 28 0	55 8 0	67 43 ·2	— 9
Kyschitim,.........	57 58 0	55 37 0	68 45 ·9	— 12
Orenburg,.........	52 46 15	51 46 0	64 40 ·7	— 25
Uralsk,.............	49 2 0	51 11 0	64 19 ·3	— 28
Saratov, ...	43 44 0	51 31 0	64 40 ·9	Oct. 4
Sarepta, ...	41 59 0	48 50 0	62 15 ·7	— 9
Astrakhan, ...	45 45 0	46 21 0	59 58 ·3	— 20
Birutschicana,*...	45 18 0	45 44 0	59 21 ·6	— 15
Woronesch, ...	36 54 0	51 39 0	65 12 ·0	— 27

* An island in the Caspian Sea.

The following are some of the most recent measures of the dip of the needle: —

	Dip of the Needle.		
Göttingen, June 23, 1832, Gauss	68°	22′	52″
Pekin, June, 1831	54	48	9
Point Turnagain, 1821, Franklin	86	56	9
Fort Enterprise, 1821, ditto	86	58	0
Cumberland House, 1821, ditto	84	35	0
Ditto ditto, 1833, Back	80	49	0
York Factory, 1821, Franklin	79	29	0
New York, 1833, Back	73	14	0
Montreal, ditto, ditto	77	49	0
Isle à la Crosse, 1821, Franklin	84	13	0
Ditto, 1833, Back	80	35	0
Fort Chipeweyan, 1821, Franklin	85	23	0
Ditto, 1833, Back	81	52	0
Fort Resolution, 1833, ditto	84	30	0
Fort Reliance, 1834, ditto	84	24	0
Musk ox Rapid, 1834, ditto	86	13	0
Rock Rapid, 1834, ditto	87	54	0
Point Beaufort, 1834, ditto	88	13	0
Montreal Island, 1834, ditto	87	45	0
Point Ogle, 1834, ditto	87	26	0
Edinburgh, Greenhill, 1832, Forbes	71	37	0
Reykiavik, June 3, 1836	70	4	0

On the Progressive Change in the Dip of the Needle.

The dip of the needle, like the variation, undergoes a continual change, increasing in some parts of the world, and diminishing in others. The following table shews the change which has taken place in the dip at Paris, from 1671 down to 1829.

Year.	Dip.	Year.	Dip.
1671	75° 0′	1818	68° 35′
1754	72 15	1819	68 25
1776	72 25	1820	68 20
1780	71 48	1821	68 14
1791	70 52	1822	68 11
1798	69 51	1823	68 8
1806	69 12	1824	68 7
1810	68 50	1825	68 0
1814	68 36	1826	68 0
1816	68 40	1829	67 41
1817	68 38		

Arago.

The following table shews the changes of the dip at London since 1720.

Year.	Observed.		Computed.
1720,	74° 42′	Graham.	76° 27′
1773,	72 19	Heberden.	73 40
1780,	72 8	Gilpin	73 18
1790,	71 53	Ditto.	72 39
1800,	70 35	Ditto.	71 58
1810,			71 15
1818,	70 34	Kater.	70 34
1821,	70 3	Sabine.	
1828,	69 47	Ditto.	69 43
1830,	69 38	Kater.	
1833,			69 21

The last column in the table was calculated by Professor Barlow, by his formula, 2 cotan. πL = tan. dip, or that the tangent of the dip is equal to double the tangent of the magnetic latitude.

The progressive variation in the dip of the needle is, as M. Humboldt has shewn, the necessary consequence of a change in the magnetic latitude, arising from the motion of the nodes of the magnetic equator modified by the form of this curve; and M. Morlet has applied

the same principle to account for the variations of the dip in different parts of the globe.

Humboldt and Arago have endeavoured to deduce the annual diminution of the dip occasioned by the motion of the magnetic equator. By comparing the observations of 1778 and 1810 for Paris, the annual diminution was about 5′, whereas, from those of 1820 and 1825, it appears to be only 3′·3. The observations at Turin from 1805 to 1826 give 3′·5, and those of Florence 3′·3.

Besides the progressive variation of the dip, Hansteen has found, from a series of observations made with a dipping needle by Dollond, that the dip during the summer was about fifteen minutes greater than during the winter, and about four or five minutes greater in the forenoon than in the afternoon.

SECT. III.—*On the Intensity of Terrestrial Magnetism.*

The determination of the intensity of the earth's magnetism at different points of its surface, and of the changes which it undergoes, either progressively or at different times of the day and different seasons of the year, has become one of the most important practical problems connected with the physical condition of the globe.

The method of determining this important element by the number of oscillations of the needle was first suggested by Graham, and brought to perfection by Coulomb, Humboldt, and others. If a needle whose axis of suspension passes through its centre of gravity, and which has its north polar and south polar magnetism equal, and similarly distributed, is made to vibrate by turning it from its position, and allowing it to receive that position by a series of oscillations, it is obvious that the earth's magnetism acts with equal force on each half, and that both these forces tend to draw the needle into

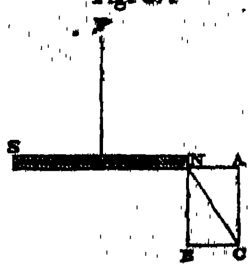
the magnetic meridian. The greater the magnetic force, the more quickly will the needle oscillate and recover its primitive position. The needle is, in short, in the same circumstances as a pendulum, oscillating by the action of gravity; and, as in this case, the forces are as the squares of the number of oscillations made in the same time.

Let us now suppose, to take the simplest case, that we make the dipping needle oscillate in the plane of the magnetic meridian, round the line of the dip, and that when the experiment is performed at the equator, the number in a second is 24, while in another place it is 25; then the intensities of the magnetic force at these places is as 25^2 to 24^2, or as 625 to 576, or as 1·085 to 1·000. By carrying the same needle to different parts of the earth, the magnetic intensity at these places will be found from the number of its oscillations.

In the application of this method there are various practical difficulties, particularly the necessity of its resting upon knobs, edges of steel, or agate, during its oscillation, which do not exist if we make a needle oscillate horizontally when suspended by a fine fibre of silk. This latter method has, therefore, been the one universally employed, though a little calculation is necessary to obtain the intensity of terrestrial magnetism, from the number of oscillations which are performed.

Let N S be a magnetic needle suspended horizontally by a fibre of silk P, and let N C be the line of the dip, or A N C = D the dip itself. Then if F is the force of terrestrial magnetism acting upon the oscillating needle, and tending to bring it to rest, we may decompose this force into two, viz. one, N B, acting in a vertical direction, and which,

Fig. 57.



being counteracted by the suspended force, has no tendency to affect the needle; and the other, N A, acting horizontally, and tending to direct the needle, and cause it to oscillate. This force N A is the cosine of A N C, the dip D. Hence the force N A will be equal to $F \times \cos. D$. For any other place where the magnetic intensity is F' and the dip D', the effective force will be $F' \times \cos. D'$; and if we call N the number of oscillations made in a second at the first place, and N the number at the second, we shall have $F \times \cos. D : F' \times \cos. D' = N^2 : N'^2$, and the ratio of the magnetic intensities at the two places, or $\frac{F}{F'} = \frac{N^2 \cos. D}{N'^2 \cos. D'}$.

In this way, observations on the magnetic intensity have been made in almost every part of the world, as shewn in the following table, drawn up by Professor Hansteen, and containing observations made principally by himself and his friends. The third column contains the number of seconds in which 300 vibrations of the needle are performed.

Places.	Lat.	Long. from Ferro.	Time of 300 Oscillations.
Berlin,	52° 32′	31° 2′	760″·03
Paris,	48 50	20 0	758·03
London,	51 31	17 34	775·34
Edinburgh,	55 58	14 29	820·26
Liverpool,	53 22	14 43	801·6
Oxford,	51 46	16 24	779·8
Christiansand,	58 8	25 43	820·3
Mandal,	58 1	25 0	814·3
Tjøs,			816·8
Carlscrona,	56 7	33 18	785·3
Ystad,	55 26	31 28	779·8
Sarim,	52 7	34 48	746·1
Glogau,	51 43	33 36	748·8
Carolath,	51 46	33 37	752·7
Zelgos,	53 11	32 48	759·7
Dantzig,	54 21	36 18	770·4
Marienburg,	54 2	36 42	766·0*

Places.		Lat.	Long. from Ferro.	Time of 300 Oscillations.
Goslina,		52° 34′	34° 43′	759″·7
Aüstrin,		52 35	32 40	762·4*
Christiana,		59 55	28 25	814·76
Friedrichshall,	1819	59 8	29 4	821·7*
	1822			830·3
Quistrum,	1819	58 27	29 25	816·1*
	1820			815·4
Hede,		57 58	29 48	810·8
Gottenbarg,	1819	57 42	29 38	812·2*
	1820			812·1
Quibille,		56 47	30 30	791·6*
Helsingburgh,	1820	56 3	30 23	791·1*
	1820			790·0*
Helfingöer,	1820	56 2	30 18	789·8*
	1820			784·6*
Copenhagen,		55 41	30 15	788·08
Friedrichsburg,		55 56	29 58	785·9
Soroe,	1820	55 27	29 4	790·6
	1822			790·4
Skieberg,		59 14	28 51	826·7
Kongsberg,	1820	59 40	27 20	845·4
	1821			839·3
				845·1
				837·8
	1821			859·5
Bolkesjö,		59 43	27 0	834·9
Vik,				836·8
Tindosen,				834·6
Oernäs,				829·1
Ingolfsland,		59 53	26 28	833·4
Miland,		59 56	26 36	838·4
Tind,		60 0		835·7
Midböen,				836·8
Rögsland,				838·0
Nörsteböe,		60 20	26 17	839·8
Holmekjärn,		60 17	25 24	832·8
Maursäter,		60 25	25 3	820·3
Eifford,				852·6
Ullensvang,		60 20	24 18	840·7
Johnnäs-Tangen,				848·8
Gjermundshafen,		60 3	23 52	840·2
Kaarevigen,		59 45	23 7	838·2
Findas,		59 45	22 54	801·7
Siggens,				824·2
—				837·4
Folgeröe,		59 48	22 50	833·9

Places.	Lat.		Long. from Ferro.		Time of 300 Oscillations.
Engesund, . .	59°	55′	22°	53′	840″·7
Beckkervig, . .	60	1	22	50	851·0
Bratholmen, .	60	21	22	47	839·5
Bergen, . . .					
Fort Friedrichsberg,	60	24	22	57	850·1
Friedrichsberg, .					850·5
Lunggaards Sec, .					849·3
Lyderhorn, 1255 ft.					843·7
Lovstakken, 1524 ft.					904·7
Haugs, . .	60	27	23	18	845·2
Bolstadörn, . .	60	32	22	43	847·7
Evanger, . .	60	33	23	52	845·9
Vossevangen, . .	60	38	24	10	850·6
Tvinde, . .	60	42	24	11	849·1
Staleim, . . .	60	52	24	19	848·9
Leirdalseren, .	61	10	25	29	856·3
Leirdals, . .	61	8	25	30	852·2
Maristuen, . .	61	2	25	54	855·3
Nyestuen, . .	61	8	25	59	853·2
Vangs, . .	61	6	26	23	845·6
Slidre, . . .	61	5	26	49	853·9
Tumlevold, . .	60	51	27	38	843·7
Grans, . . .	60	22	28	12	842·3
Moe, . .	60	14	28	11	848·3
Sundvold, . .	60	4	28	7	842·6
Johnsrud, . .	59	57	28	19	841·5
Hurdal, . . .	60	26	28	49	827·3
Trogstad, . .	60	8	28	56	823·8
Sunbye, 1822	59	36	28	35	826·8
Sooner, . . .	59	32	28	25	827·8
					828·1
Boe, . .	59	7	29	7	828·2
Altorp, . .	58	53	29	54	816·3
Oedskjolds-Moen, .	58	50	29	52	816·0
Elleoen, . .	59	19	28	20	826·7
Godtskjär, . .	57	26	29	48	809·9
Korset, . . .	58	49	27	12	824·5
Helegraae, . .	58	59	27	34	822·7
Stubberud, . .	59	4	27	55	818·9
Solerud, . .	59	21	28	9	826·5
Konnerud-Kollen, 1823					875·5
Auestad, . .	59	49	27	58	852·1
Bragernäs, . .	59	49	27	53	848·6
Ravnsborg, . .	59	52	28	17	820·5*
Friedrichsvärn, 1824	59	0	27	44	813·5
Friedrichshavn, .	57	27	28	13	808·1

Places.		Lat.		Long. from Ferro.		Time of 300 Oscillations.
Aalborg,		57°	3′	27°	36′	806″·0
Sporring,						799·9
Aarhuus,		56	10	27	54	796·0
Hovedkrug,						798·3
Weile,		55	43	27	12	793·9
Apenrade,		55	8	27	6	786·4
Gehlau,						787·9
Schleswig,		54	31	27	15	783·0
						785·5
Remmels,		54	7	27	18	783·0
Elmshorn,		53	46	27	18	779·1
Altona,		53	33	27	33	776·1
						774·9
Berlin,		52	32	31	2	760·4
						759·9
Lubeck,		53	51	28	21	776·2
Ploen,		54	9	28	6	780·5
Preetz,		54	13	27	57	779·0
Kolding,		55	27	27	0	789·1
Odensee,		55	24	27	59	793·7
Buskerud,						845·5
Johnsknuden,						961·3
Skrimfjeld,						891·3
Rolloug,		59	59	27	5	844·0
Synehovedet,						846·3
Eje,		60	6	26	53	838·5
Ejesfjeld,						881·2
Daglio,		60	18	26	26	887·4
Torpe,		60	40	26	47	841·5
Haavi,	June,	61	7	26	42	851·2
	Sept.					850·4
Urland,		61	0	24	55	849·2
Vess,	June,	60	38	24	10	856·5
	Sept.					845·9
Age-Nuten,						842·7
Vigen,		60	18	24	5	850·7
Bergen,		60	24	22	57	
Nyegaard,						857·1
Floifjeldet,						854·7
Lövstakken,						844·2
Friedrichsberg,						851·7
Lindaas,		60	43	23	8	843·5
Evenvig,		68	58	23	8	850·6
Ytre-Sulen,		61	4	22	45	852·1
Stensund,		61	8	22	52	852·9
Pollefjeld,						861·8

Places.		Lat.		Long. from Ferro.		Time of 300 Oscillations.
Askevold,		61°	24′	23°	7′	861″·1
Vilnas,		61	22	22	58	860·7
Sougesund,		61	22	23	11	861·7
Alden,		61	22	22	50	850·7
Bueland,		61	17	22	44	851·2
Sveen,						856·4
Quamshest,						849·8
Forde,	July,	61	32	23	48	858·9
	Aug.					858·8
Jolster,		61	35	24	10	848·6
Gloppen,		61	51	24	6	861·9
Indvig,		61	49	24	34	860·4
Horningdal,		61	59	24	33	862·6
Hälsylta,		62	7	24	54	864·8
Nordal,		62	18	25	13	870·3
Veblungsnäs,		62	31	25	39	868·3
Fladmark,						862·9
Nyestuen,						862·7
Fogstuen,		62	5	27	9	856·9
Jerkin,		62	12	27	29	846·5
Foldal,		62	7	27	57	855·5
Kongsvold,		62	18	27	36	860·0
Drivstuen,		62	26	27	41	858·0
Riise,		62	31	27	41	858·1
						859·8
Näverdal,		62	42	28	6	858·7
Stoa,		62	32	28	21	860·4
Göra,		62	35	27	2	862·1
Tofte,		61	58	27	10	859·3
Vange,		61	51	27	4	860·8
Vinje,		60	52	24	22	848·2
Nyuestuen,		61	8	25	59	852·1
Skougstad,		61	10	26	12	858·7
Smedshammer,		60	29	28	14	841·9
Sundvold,		60	4	28	7	839·2
Carlscrona,						785
Breslau,						741
Stockholm,						815
Hernösand,						850

The principal intensities computed from these observations will be found in our table of the dip, given above.

It is obvious from these data that the magnetic intensity increases from the equator to the poles, and the law of variation is shewn in the following table :—

Dip of the Needle.	Magnetic Intensity.
0°	1·0
25	1·1
45	1·2
64	1·3
73	1·4
76⅔	1·5
81	1·6
86	1·7

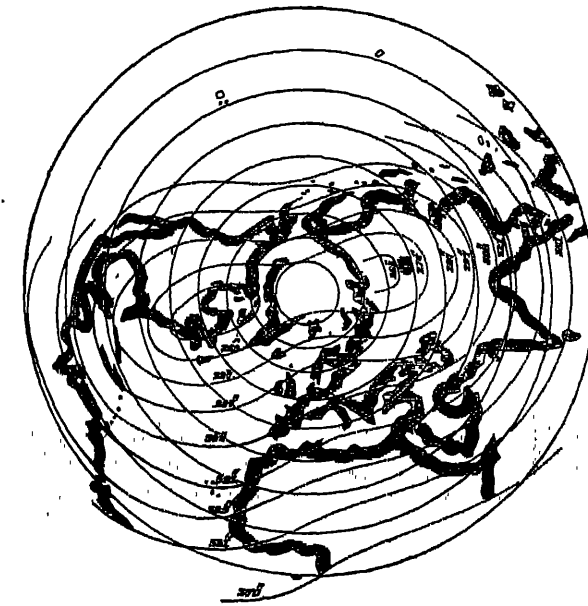
M. Hansteen has projected upon a map of the globe the lines passing through all the places in which the intensity has the same value. These lines he calls *isodynamic lines,* or those of *equal force,* and they are, generally speaking, nearly parallel to each other, and to the lines of equal dip.

Many valuable observations on the intensity of the earth's magnetism were made during the numerous arctic expeditions which were sent out by the British Government; but Professor Hansteen being extremely desirous of establishing, by direct observations of his own, the existence of the secondary magnetic pole, which he believed existed in Siberia, set out for this purpose, at the expense of the Norwegian Storthing, and with every encouragement and assistance from the Russian government. The results of this expedition exceeded his most sanguine expectations. The Russian Academy of Sciences have, in consequence of Professor Hansteen's scientific journey, been induced to take a new interest in the subject of terrestrial magnetism, which exhibits such important features throughout the Russian empire: and the Russian government has established regular observatories in different parts of its vast dominions, for making magnetical experiments. The Russian empire is actually traversed by *two* lines of no variation, and it is proposed to determine with great precision, every ten years, the exact position of these two lines. Near the

first of them, which traverses European Rusia, Petersburg, Moscow, and Kasan, are situated; and near the second, which passes through Siberia, is situated Kiachta and Nizni-Oudinsk.

The principal observations made by Hansteen in Siberia have been laid down in a map of the northern

Fig. 58.



hemisphere by Captain Sabine, along with other observations made by himself and Humboldt. In this map, of which the prefixed figure is a copy, it is exceedingly interesting to observe the isodynamic lines surrounding the two northern magnetic poles, and forming a series of returning curves similar to lemniscates, and which

may be calculated by the formulæ of Sir David Brewster, already given in the History of Magnetism.

In this map the *American* pole is situated nearly in 60° of N. lat. and 80° of W. long.; and the *Asiatic* pole in 60° N. lat. and 100° of E. long. The black lines pass through the places where the magnetic intensity was observed to be equal, and the dotted parts of the same curves indicate the probable direction of the lines where observations have not yet been made. The lines round the American pole are laid down principally from Captain Sabine's observations, and those round the Asiatic pole from the recent observations of Hansteen. The following is the account given of the different isodynamical lines in the figure, by Captain Sabine.

The *first* curve, or that nearest the magnetic poles, is that in which a magnetic needle which performs *n* oscillations in 300″ in London, performs the same number in 269″ round the Asiatic pole. This curve contains a smaller space than the corresponding curve round the American pole, which proves the inferior activity of the former pole. Hansteen traced the south part of this curve below lat. 60°, from the river Jenisei, to the 115th degree of W. long., that is, 25° beyond the Jenisei, and to lat. 60°, where it takes a direction almost due north.

The *second* curve, or that in which the same number *n* oscillations are performed in 278 seconds, goes round both the American and Asiatic poles, including both within its area. It passes to the north-west of Melville Island, and to the north-east of some stations on the west coast of Greenland; and it cuts the American coast between the Havannah and New York. Dr Erman, who accompanied Hansteen into Siberia, traced the same curve from the embouchure of the Oby, in N. lat. 68°, and E. long. 70°, following the direction of the river Mina as far as 60° N. lat. The curve here gradually bends to the east, and

after passing between Tobolsk and Narym, it was again detected by M. Hansteen at Kainsk, a few degrees to the south of Lake Baikal.

The *third* curve, or that in which *n* oscillations are performed in 287″, is drawn on the American side, from observations made at the Havannah, at the Pendulum Isle on the east coast of Greenland, in N. Lat. 74° 5′, and between Spitzbergen and Hammerfest, near the North Cape. This curve, according to Hansteen, enters Europe between Archangel and Nova Zembla; and he met with it again between Moscow and Tobolsk, at 56½° of E. long. and 57½°.of N. lat.

The *fourth* curve, or that in which *n* oscillations are performed in 297 seconds, passes near Jamaica, where the oscillations were performed in 294 seconds, and, after traversing the north of Britain, it enters Norway to the south of Bergen. Advancing eastward, it passes between Stockholm and Torneo, and thence by St Petersburg and Moscow.

The observations of Professor Hansteen do not extend farther south than these lines, and therefore Captain Sabine has laid down in the map the lines in which *n* oscillations are performed in 308, 321, 335, 351, and 370 seconds, from his own observations and those of Humboldt. The lowest number of seconds in which *n* oscillations are performed is at the magnetic poles, where it is nearly 262 or 263, and the greatest, 370, the time in which they are performed at the equator.

We have stated that the isodynamical lines are nearly parallel to those of equal dip. This is the case in Scotland; but towards the east, in Norway and Sweden, the lines of equal intensity bend more to the north, and cut the former; and also, under the same line of equal dip, the intensity is weaker to the east than to the west. Hence M. Hansteen has found that the pole of the lines of equal dip lies in 71° of lat., and 102° of long., while the

pole of intensity is in 56° of lat., and 80° of long. west of Paris. The first of these determinations coincides very nearly with the pole of Commander Ross, where the dip was 90°. The latest observations made during the arctic expeditions from England, and also those by Hansteen and Erman in Siberia, prove beyond a doubt the accuracy of the earlier conclusion of Hansteen, that the lines of equal intensity and equal dip are not parallel. Humboldt discovered the node of the magnetic equator with the isodynamical curve in 7° of S. lat., and 81° of long. west of Paris. He traced this last line to the west of the Cordilleras of the Andes, and along the coast of Peru, towards Kasma and Fluormay, even to the 10th degree of S. lat. M. Adolphus Erman found in Siberia, that the isodynamic line, where the intensity is 1·60 (that of the equator being 1·00,) directs itself also from north to south with a slight inclination to the south-east. He observed this line *cut almost at right angles the curves of equal dip*, and then descend from the north-north-west to the south-south-east, from Ochotsk, near the mouths of the Oby, to Tomsk. M. Humboldt is of opinion that the isodynamical line and the Peruvian node of the magnetic equator have been carried, since his voyage, from east to west; and he informs us that M. A. Erman, in the 135th degree of long. west of Paris, and in the magnetic equator, found that the intensity of the magnetic forces was sensibly the same as he had found them twenty-six years before on the magnetic equator in Peru.

As the intensity of terrestrial magnetism at different places is not a function of the dip at these places, and the isodynamic lines are not parallel to those of equal dip, it is probable that different points of the equator have not the same magnetic intensity. "Having carried," says Humboldt, "the same needle or needles compared with them, from Paris to Mexico, to the magnetic equator in Peru, to Berlin, to Petersburg, to the shores of the

Caspian, and to the north of Asia, I have expressed the magnetic intensities at these places, by taking for unity the intensity which I find on the magnetic equator in Peru, or rather in the intersection of this equator with the isodynamical line of minimum intensity. On this supposition, I find for Paris 1·3482, for Milan 1·3121, for Naples 1·2745. The very valuable observations of M. Rossel, at Surabaya in Java, and those of Captain Sabine near St Thomas, 5° north of the equator, indicate that the magnetic intensity is less on the magnetic equator near the west coast of Africa (long. 40. 24. W.,) and in the great Italian archipelago, than in the portion of the magnetic equator which crosses Peru. Besides, M. A. Erman has observed, that on the east coasts of South America the intensities are much weaker at the same distances from the south terrestrial pole than on the west coasts. The intensity 1·00, found to the west of the new continent, on the magnetic equator in the South Sea, in 135° of west longitude and 1° 55′ of south latitude, shews itself on the coasts of Brazil towards the 38th degree of south latitude, while the dip is there even more than 37° south. It appears to me more probable that the minimum intensity at the surface of the earth is to the maximum, not as 1 to 1·6 or 2, as has been supposed, but even much beyond the ratio of 1 to 2·6."

Observations are yet wanting to determine in what manner the intensity varies with the height. Humboldt is of opinion that it decreases, thus confirming the deductions of Kupffer. *

By combining all the observations of intensity from 179° to 183°, M. Hansteen has drawn the conclusion, *that the total magnetic intensity is smaller in the southern than in the northern hemisphere.* M. Duperrey has confirmed this result. According to the investigations of Biot, the

* See Sect. iv. p. 275.

natural magnetic intensity, or I, is $= 2\,A \cdot \sqrt{\frac{1}{4-3\sin.^2\delta'}}$.

and that of the horizontal needle $= 2\,A \cdot \sqrt{\frac{1}{3+\sec.^2\delta'}}$

δ being the dip; but these formulæ presuppose that the earth is perfectly homogeneous, and of course they cannot be verified by insulated observations. M. Duperrey has therefore been obliged, in order to bring all these observations into this state, to take the mean intensity of the terrestrial equator, and of each of the parallels of the globe, and to multiply the circumference of each curve by its intensity in order to have the total intensity, and then to take the mean of the total intensities of the corresponding parallels in each hemisphere. In this manner he obtained all the points of the curve which represents the law of the increase of the magnetic forces from observation. The curve thus traced, when compared with that which is calculated by the formula of M. Biot, does not deviate from it above 0·015 of the intensity, supposing the intensity at the magnetic equator in Peru to be 1. He has found also that the surface of the north magnetic hemisphere is to that of the south one in the ratio of 1·0000 to 1·0152, a ratio which is the same as that of the total intensity of the south terrestrial hemisphere to the total intensity of the north terrestrial hemisphere; and he hence concludes, that *the surfaces of the two magnetic hemispheres are proportional to the intensities of the two terrestrial hemispheres.*

On the Monthly and Daily Change of Intensity.

The magnetic intensity, like the other elements of terrestrial magnetism, suffers monthly and diurnal changes. By means of the vibrations of a needle delicately sus-

pended, M. Hansteen found that the *minimum* of the daily change of intensity is between ten and eleven in the forenoon, and the *maximum* between four and seven in the afternoon in May, and about seven in June. The intensity is a maximum in December, and a minimum in June. The greatest monthly change in the intenstiy is a maximum in the months of December and June, about the time when the earth is in its perihelion and aphelion. It is a minimum near the equinoxes, or when the earth is at its mean distance from the sun. The greatest daily change is least in the winter and greatest in the summer, the greatest difference of the annual change of intensity is 0·0359. M. Hansteen has likewise found, that the magnetic intensity is diminishing in Europe, and that the decrease is greater in the northern and eastern, than in the southern and western parts, an effect which he conceives to be produced by the motion of the Siberian pole towards the east. At port Bowen, Captain Parry observed an augmentation of the magnetic intensity to take place from the morning till the afternoon, and a diminution of it from the afternoon till the morning. These results of Hansteen have been confirmed by Mr Christie,* who has shewn that the terrestrial magnetic intensity is a minimum between ten and eleven o'clock in the morning, the time nearly when the sun is in the magnetic meridian; that it increases from this time until between nine and ten o'clock in the evening, after which it decreases, and continues decreasing during the morning, till it reaches its minimum between ten and eleven. These results were deduced from observations made in May, *within doors*, to determine the positions of the points of equilibrium at which a magnetic needle was retained, at different hours during the day by the joint action of two bar magnets, and of terrestrial magnetism, reduced to their true positions at the standard temperature (60°) of

* *Phil. Trans.* 1825, p. 49—51.

the magnets. As this change in the position of these points was produced by the change in the magnetic intensity, Mr Christie thus obtained accurate measures of the last of these elements by means of the formula

$$M - F\,(\cdot004690814 + \cdot000829329 \cos.^2 \varphi) = 0,$$

in which M is the horizontal part of the terrestrial magnetic force, acting on the north arm of the needle in the line of the dip, F the force with which a pole of the needle is repelled from a pole of the same name of either magnet, or attracted towards that of a contrary name at the unity of distance, and φ the angle which the axis of the needle makes with the meridian, or the azimuth of the point of epuilibrium.

Mr Christie repeated his observations *in the open air* in June, and from these it appears that the minimum intensity happened nearly at the time the sun passed the magnetic meridian, and rather later than in May, which was also the case with the time of the sun's passage over the meridian. The intensity increased until about six o' clock in the afternoon, after which it appears to have decreased during the evening, and to have been decreasing from an early hour in the morning. Mr Christie has given the following interesting view of Hansteen's results and his own.

Intensity deduced from Hansteen's Observations in 1820.			Intensity deduced from Mr Christie's Observations in 1828.		
Time.	May.	June.	Time.	May.	June.
8 *h.* 0′ A.M.	1·00034	1·00010	7 *h.* 30′	1·00114	1·00061
10 30	1·00000	1·00000	10 30	1·00000	1·00000
4 0 P.M.	1·00299	1·00251	4 30	1·00175	1·00223
7 0	1·00294	1·00304	7 30	1·00220	1·00239
10 30	1·00191	1·00267	9 30	1·00231	1·00209

The principal difference between these results is, that in Mr Christie's observations the intensity seems

to diminish more rapidly in the morning, and increase more slowly in the afternoon, than it does in those of Hansteen.

The following table shews the horizontal magnetic intensity at Göttingen, as determined by Professor Gauss, in different months of 1832, with great accuracy.

1832.	Horizontal Intensity.	1832.	Horizontal Intensity.
May 21.	1·7820	July 25, 26,	1·7845
— 24.	1·7694	Sept. 9.	1·7764
June 4.	1·7713	— 18.	1·7821
— 24–28.	1·7625	— 27.	1·7965
July 23, 24.	1·7826	Oct. 15.	1·7860

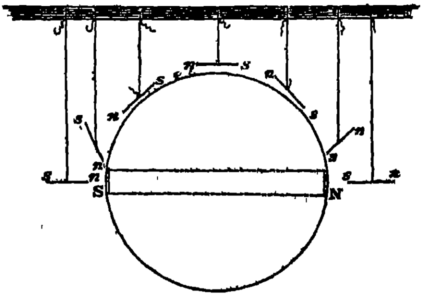
In order to obtain from these numbers the absolute magnetic intensity, to compare them with the results in Hansteen's table, they must be multiplied by the secant of $68^\circ\ 22'\ 22''$, the dip at Göttingen on the 23d June, 1832.

SECT. IV. — *On the Nature and Causes of the Earth's Magnetism.*

The phenomena described in the preceding sections afford abundant evidence that the earth is in some way or other magnetic; but what is the nature of its magnetic condition, or from what cause it derives its origin, are points which it is not easy to determine. The earliest and the most natural supposition is that of Dr Gilbert, that the earth contains within itself a powerful magnet, lying in a position which nearly coincides with its axis of rotation. In this case, the pole of this magnet, which acts in our northern hemisphere, must have south polar magnetism, as it attracts the north pole of the needle; while the pole in the southern hemisphere must have north polar magnetism, as it attracts the south pole of

the needle. That this hypothesis would, generally speaking, represent the ordinary phenomena of terrestrial magnetism, may be easily shewn by placing a bar-magnet within a terrestrial globe, and observing the phenomena exhibited by a small needle suspended at its centre of gravity by a fine thread or fibre. As the magnet is placed out of the axis of rotation, the needle in the northern hemisphere will always point to the north end of the enclosed magnet, exhibiting all the phenomena of the variation of the needle, as usually observed. The general phenomena of the dip will also be exhibited, as shewn in the annexed figure, where N S is the direction of the enclosed magnet, shewn by dotted lines, S being the northern magnetic pole, and N the southern and *ns*, *ns*, small needles suspended by fibres *f*, *f*, *f*.

Fig 59.



The needle has no dip at the equator, because each pole is equally attracted by the corresponding poles of the enclosed magnet, and at the poles S N the dip is 90°, as observed at the northern magnetic pole by Commander Ross. At latitudes intermediate between the magnetic equator and the magnetic poles, the dip has an intermediate value.

In the same manner as a common bar-magnet communicates magnetism to a piece of soft iron held near it, the supposed magnet in the earth communicates magnetism to a soft iron bar held in the magnetic meridian, and parallel to the dipping needle, which in this

country is not far from a vertical position. The soft iron is temporarily a magnet, exactly like the soft bar in the presence of a real magnet, and possesses the very same properties.

In the progress of discovery, however, it has been found, that the phenomena of the dip and the variation are more complex than this hypothesis will allow us to suppose; and in measuring the magnetic intensity in Siberia, Hansteen has proved that there is another magnetic pole in that country, which regulates the magnetic phenomena. In order to account for these, we must therefore suppose another magnet passing through the globe in the direction of a diameter whose pole coincides with the Siberian magnetic pole. But even this addition to the hypothesis of Gilbert will not explain the phenomena, unless we resort to the absurd assumption of Halley, who gives rotatory movements to magnetic spheres placed in the interior of the globe.

A more sober and philosophical hypothesis is one which has been long gaining ground, and which recent discoveries have rendered still more probable. According to this hypothesis, the magnetism of the earth is not that of a magnet, but that of a sphere or spherical shell of iron on which magnetism is induced. The difference between these two magnetic states is very great. In regular magnets, the centres of action are placed at their extremities or poles; but in masses of iron, either hollow or solid, either regular or irregular, the centres of action are always coincident with the centre of attraction of the surface of the mass. When the observations on the variation and dip of the needle became numerous and accurate, philosophers soon perceived that they could not be explained by the action of two magnetic poles at a distance from each other. M. Biot had the merit of first viewing the subject in this light, and he at length came to the conclusion, that the nearer the poles were

taken to each other, the greater was the agreement between the computed and observed results; and by assuming the two centres as indefinitely near to each other in the centre of the earth, the coincidence between observation and calculation was as great as could be expected. Now it is a remarkable fact, that Mr Barlow discovered, as we have already seen, that such a coincidence in the centre of action actually takes place in all bodies which are magnetic by induction, such as iron spheres or shells; and he has applied this principle to account for the various phenomena of the dip and variation of the needle. Almost all the philosophers who have since investigated the subject have adopted this idea; and the only difficulty which attaches to it is, where to find the cause by which the earth's magnetism is induced. The following speculations on this curious subject are hazarded by M. Hansteen, in his work on the magnetism of the earth.

"For these reasons, it appears most natural to seek their origin in the sun, the source of all living activity; and our conjecture gains probability from the preceding remarks on the daily oscillations of the needle. Upon this principle, the sun may be conceived as possessing one or more magnetic axes, which, by distributing the force, occasion a magnetic difference in the earth, in the moon, and all those planets whose internal structure admits of such a difference. Yet, allowing all this, the main difficulty seems not to be overcome, but merely removed from the eyes to a greater distance; for the question may be still asked with equal justice, *whence did the sun acquire its magnetic force?* And if from the sun we have recourse to a central sun, and from that again to a general magnetic direction throughout the universe, having the milky-way for its equator, we but lengthen an unrestricted chain, every link of which hangs on the preceding link, no one of them on a point

of support. All things considered, the following mode of representing the subject appears to me most plausible. If a single globe were left to move alone freely in the immensity of space, the opposite forces existing in its material structure would soon arrive at an equilibrium conformable to their nature, if they were not so at first, and all activity would soon come to an end. But if we imagine another globe to be introduced, a mutual relation will arise between the two; and one of its results will be a reciprocal tendency to unite, which is designated, and sometimes thought to be explained, by the merely descriptive word attraction. Now, would this tendency be the only consequence of that relation? Is it not more likely that the fundamental forces, being driven from their state of indifference or rest, would exhibit their energy in all possible directions, giving rise to all kinds of contrary action? The electric force is excited, not by friction alone, but also by contact, and probably also, though in smaller degrees, by the mutual action of two bodies at a distance; for contact is nothing but the smallest possible distance, and that, moreover, only for a few small particles. Is it not conceivable that magnetic force may likewise originate in a similar manner? When the natural philosopher and the mathematician pay regard to no other effect of the reciprocal relation between two bodies at a distance, except the tendency to unite, they proceed logically, if their investigations require nothing more than a moving power; but should it be maintained that no other energy *can* be developed between two such bodies, the assertion will need proof, and the proof will be hard to find.

"I reckon it possible, therefore, that, by means of the mutual relations subsisting between the sun and all the planets, as well as between the latter and their satellites, a magnetic action may be excited in every one of those globes whose material structure admits of it, in a direc-

tion depending on the position of the rotatory axes with regard to the plane of the orbit. Each of the planets might thus give rise to a particular magnetic axis in the sun; but as their orbits make only small angles with the sun's equator and each other, these magnetic axes would, perhaps, on the whole, correspond with the several rotatory axes. Such planets as have no moons would, on this principle, have but one magnetic axis; the rest would, in all cases, have one axis more than they have moons, if those different axes, by reason of the small angles which the orbits of their several moons form with each other, did not combine into a single axis. The conical motions by which the rotatory axes of the planets are carried round the pole of the ecliptic (the precession in the earth,) joined to the revolving motion of the orbits about the sun's equator, (which occasions the present diminution in the obliquity of the ecliptic,) might, perhaps, in this case, account for the change of position in the magnetic axis. It would greatly strengthen this hypothesis, if the above great magnetic period, after the lapse of which both axes again assume the same position, should in fact be found to coincide with the period of the precession, which, however, seems a little doubtful."

Such was the state of speculation on this part of the subject when Hansteen published his work on the magnetism of the earth. The poles of our globe were then regarded as the coldest parts on its surface; and no conjecture even had been hazarded regarding the connection between the phenomena of terrestrial temperature and terrestrial magnetism, till Sir David Brewster proved, from an immense number of meteorological observations, that there were in our northern hemisphere two poles of maximum cold; that these poles coincided with the magnetic poles; that the circle of maximum heat, like the magnetic equator, did not coincide with the

equinoctial line; that the isothermal lines, and the lines of equal magnetic intensity, had the same general form surrounding and enclosing the magnetic poles and those of maximum cold; and that, by the same formula, *mutatis mutandis*, we could calculate the temperature and the magnetic intensity of any point of the globe. These views we have referred to more fully in the history of magnetism.

The monthly and daily changes in the intensity of terrestrial magnetism, and in the dip and variation of the needle, had led Canton and others to ascribe these changes to the action of the sun; and Captain Duperrey, in his paper on the magnetic equator, has ascertained, that the points of this great circle, or those where the magnetic intensity is a minimum, are also the warmest points of each meridian, or that the thermal and the magnetic equator are connected, as we had already proved to be the case with the thermal and magnetic poles. Captain Duperrey likewise attributes the differences in the magnetic intensities of different places to their difference of temperature; and he remarks, that in comparing the isothermal and the isodynamic lines, he has found a remarkable analogy in their curvatures, and particularly in the direction of their concavities and convexities. In support of these views, Captain Duperrey refers to the changes in the daily variation, as following the movements of the sun; and he infers that the southern hemisphere of our globe is a degree colder than the northern hemisphere.

But though it is now placed beyond a doubt, that the phenomena of temperature and magnetism are closely connected, and that the latter are powerfully influenced by the former, yet various questions arise, which it is very difficult to answer.

1. Have the phenomona of terrestrial magnetism an

electric origin; that is, is the magnetism developed by electro-magnetic or thermo-magnetic causes? or,

2. Are the phenomena owing to the diffusion of iron or other magnetic metals through the solid mass of our globe, in which magnetism is induced by some exterior cause?

The electro-magnetic hypothesis, which was first stated by Sir David Brewster, has been ably supported by Professor Barlow, in a recent paper, (*Phil. Trans.* 1831) *On the probable Electric Origin of all the Phenomena of Terrestrial Magnetism*; in which he considers it as probable, "that magnetism, as a distinct quality, has no existence in nature." As all the phenomena of terrestrial magnetism can be explained on the supposition that the magnetic power resides on its surface, it occurred to Mr Barlow, that if he could distribute over the surface of an artificial globe a series of galvanic currents, in such a way that their tangential power should everywhere give a corresponding direction to the needle, this globe would exhibit, while under electrical induction, all the magnetic phenomena of the earth upon a needle freely suspended above it. He accordingly put this idea to the test of experiment in the following manner:

"I procured," says he, "a wooden globe sixteen inches in diameter, which was made hollow for the purpose of reducing its weight; and, while still in the lathe, grooves were cut to represent an equator, and parallels of latitude at every 4½° each way from the equator to the poles; these grooves were about an eighth of an inch deep and broad; and lastly, a groove of the same breadth, but of double the depth, was cut like a meridian, from pole to pole, half round. These grooves were for the purpose of laying in the wire, which was effected thus: The middle of a copper wire, nearly ninety feet long, and one tenth of an inch in diameter, was applied to the equa-

torial groove, so as to meet in the transverse meridian; it was then made to pass round this parallel, returned again along the meridian to the next parallel; then passed round this again; and so on, till the wire was thus led in continuation from pole to pole.

"The length of wire still remaining at each pole was bound with varnished silk to prevent contact, and then returned from each pole along the meridian groove to the equator. At this point, each wire being fastened down with small staples, the wires for the remaining five feet were bound together to near their common extremity, where they opened to form two points for connecting the poles of a powerful galvanic battery.

"When this connection was made, the wire became of course an electric conductor, and the whole surface of the globe was put into a state of transient magnetic induction, and consequently, agreeable to the laws of action above described, a neutralized needle freely suspended above such a globe would arrange itself in a plane passing from pole to pole through the centre, and take different angles of inclination, according to its situation between the equator and either pole.

"In order to render the experiment more strongly representative of the actual state of the earth, the globe, in the state above described, was covered by the gores of a common globe, which were laid on so as to bring the poles of this wire arrangement into the situation of the earth's magnetic poles, according to the best observations we have for this determination. I therefore placed them in latitude 72° north and 72° south, and on the meridian corresponding with longitude 76° west, by which means the magnetic and true equators cut one another in about 14° east, and 166° west longitude.

"The globe being thus completed, a delicate needle must be suspended above it, neutralized from the effect of the earth's magnetism, according to the principle I

employed in my observations on the daily variation, and described in the Philosophical Transactions for 1823; by which means it will become entirely under the superficial galvanic arrangement just described. Conceive now the globe to be placed so as to bring London into the zenith, then the two ends of the conducting wire being connected with the poles of a powerful battery, it will be seen immediately that the needle, which was before indifferent to any direction, will have its north end depressed about 70°, as nearly as the eye can judge, which is the actual dip in London; it will also be directed towards the magnetic poles of the globe, thereby also shewing a variation of about 24° to 25° to west, as is also the case in London. If now we turn the globe about on its support, so as to bring it to the zenith places equally distant with England from the magnetic pole, we shall find the dip remains the same; but the variation will continually change, becoming first zero, and then gradually increasing to the eastward, as happens on the earth. If, again, we turn the globe so as to make the pole approach the zenith, the dip will increase, till at the pole itself the needle will become perfectly vertical. Making now this pole recede, the dip will decrease, till at the equator it vanishes, the needle becoming horizontal. Continuing the motion, and approaching the south pole, the south end of the needle will be found to dip, increasing continually from the equator to the pole, where it becomes again vertical, but reversed as regards its verticality at the north pole."

Although the artificial globe represents very exactly on a small scale all the phenomena of terrestrial magnetism, and although, as Mr Barlow says, "he has proved the existence of a force competent to produce all the phenomena, without the aid of any body usually called magnetic;" yet he acknowledges that "we have no idea how such a system of currents can have existence on the

earth, because, to produce them, we have been obliged to employ a particular arrangement of metals, acids, and conductors." The discovery of Dr Seebeck, however, that the mere application of heat to a circuit composed of two metals,* is capable of developing the magnetic effects above described, is regarded by Professor Barlow as bringing us a step nearer to an explanation of the earth's magnetism, by referring us to the sun as the great agent of all these phenomena, and he conceives that only one link is wanting to complete the explanation. This link, however, is a very important one, and we are just as much puzzled to discover the metallic thermo-magnetic apparatus, as we are to discover the electro-magnetic one. If it could be shewn that the action of solar heat is capable of developing magnetism in particles such as those which are known to constitute our globe, the great difficulty would be removed; but until this is done, we are disposed to lean to the old though not yet exploded notion, that terrestrial magnetism is the effect of magnetic or ferruginous materials, which are disseminated through the mass of the earth, or throughout its atmosphere. This leads us to consider the second question relative to the origin of terrestrial magnetism.

2. Are the phenomena owing to the diffusion of iron or other magnetic metals through the solid mass of our globe, on which magnetism is induced by some exterior cause?

In so far as our knowledge extends, iron and other magnetic metals are not so regularly diffused as to produce the magnetic phenomena; and we are not entitled to assume the existence of any regular metallic nucleus, or regular arrangement of metallic strata, capable of producing that uniform action on the magnetic needle which is indicated by the regularity of the isodynamical lines,

* Mr Sturgeon of Woolwich has produced similar effects by the application of heat to only one metal, viz. a rectangle of bismuth only.

or those of equal magnetic intensity. That there are actual magnets within the crust of our globe, and abundance of ferruginous matter capable of producing locally magnetic phenomena, cannot be doubted; but the action of these two classes of bodies is regulated by different laws, and we can only regard them as exercising a disturbing force in rendering irregular the action of some more general cause. If the ferruginous matter which produces magnetism is situated near the surface of the earth, we should expect a diminution in the intensity when the needle is made to oscillate above the deepest parts of the ocean, where the solid crust may be many miles distant. If it is, on the other hand, deeply seated, the intensity ought to diminish greatly as we ascend in balloons, or to the tops of our highest mountains; but none of these effects are observed, and it becomes therefore very improbable that the magnetic phenomena are produced either by ferruginous matter *near the surface, or far removed from it.*

But though we cannot find the seat, or rather the intermedium, of terrestrial magnetism in the bowels of the earth, may we not, as a last resource, seek for it *in our atmosphere?* It appears to be demonstrated by the experiments of Fusinieri, of which we have given a full account in our article on ELECTRICITY, that metals, and *particularly iron*, exist in a state of vapour in our atmosphere: and hence we have a regular hollow shell of magnetic matter enveloping the earth, and capable, when magnetism is induced upon it by an exterior cause, of producing all the phenomena of terrestrial magnetism. In its undisturbed state of equilibrium, this magnetic atmosphere will act upon the needle, according to the laws which Mr Barlow found to regulate the action of an iron sphere or shell; but these laws will be modified by those which regulate the thermal state of the globe, and will be disturbed by sudden changes of temperature,

and by the various electrical agencies which exercise so powerful an influence over the meteorological condition of the atmosphere. The more violent disturbances of electrical equilibrium will fuse, and throw down in the form of meteoric stones, the metallic vapour in their vicinity. Inferior electrical actions will render their progress visible in the form of lightning and fiery meteors, arising from the heated state of the metallic particles; while still feebler electricities will, by their accompanying heat, produce the sheets of summer lightning, and the more continued and shifting phenomena of the aurora. Hence the electric sounds and other accompaniments of the aurora; hence its connection with the magnetic pole and equator; and hence the disturbance of the needle, or the *magnetic hurricanes*, as Humboldt calls them, while the regular action of the metallic atmosphere is disturbed during the prevalence of the aurora, or of thunder storms. These views receive some support from the observations of MM. Gay-Lussac and Biot, from which it appears that the intensity of terrestrial magnetism is not diminished at the height of 13,000 feet above the earth; and Mr Henwood found the magnetic intensity as strong 710 feet above the level of the sea, as at the bottom of a mine 950 feet below the same level. Kupffer, on the authority, we believe, of a single observation, has given an opposite opinion; and Saussure conceived that the intensity was less on the Col de Géant than at Geneva, but the numbers which he gives actually authorize the opposite conclusion.

From a series of observations made in July 1830, by M. Quetelet, in Switzerland, it appears, that in place of the intensity diminishing with the height, it actually increases, the increase taking place gradually (with the exception of Bonneville) in ascending from Geneva to the Col de Balme, as is shewn in the following table:

	Horizontal Intensity.
Geneva	1·0805
Bonneville	1·0765
Sallenches	1·0815
St Gervais	1·0861
Vaudagnes	1·0884
Servoz	1·0872
Mer de Glace	1·0885
Chamouni	1·0935
Col de Balme	1·0917
Martigny	1·0921
Hospice St Bernard	1·0966
Simplon village	1·0987
Domodossolo	1·0997

But an argument of still more weight may be derived from the admitted fact, that a *powerful source of magnetism actually exists in our atmosphere*, and that the south pole of the needle has a distinct connection with the source of this magnetism. This source of magnetism is the *aurora borealis*, and the south pole of the dipping needle points to the focus to which the beams of the aurora converge. These beams act as magnets, as we have seen in a previous section; the action of our magnetic atmosphere, when undisturbed by any other cause but that of temperature, tends to fix the needle in a specific direction, which varies within certain limits, depending on the ordinary changes of temperature; but when the regular magnetism of the atmosphere is disturbed by electric or other causes, the needle must necessarily be affected by the displacement or altered temperature of the magnetic matter, as exhibited in the motions and variations in the lustre of the beams of the aurora. The magnetic pole, therefore, in our hemisphere, will be a north pole attracting the south end of the needle, and creating an elevation of the south end in place of a dip of the north end.

By the aid of these views, all the magnetic phenomena of the aurora borealis, so ably described by Dr Dalton, and the disturbances of the needle, so accurately observed by M. Arago, in reference to auroræ that occurred in every part of the northern hemisphere, may be satisfactorily explained, as we have attempted to do in a preceding section.

In seeking for a cause which is capable of inducing magnetism on the ferruginous matter of our globe, whether we place it within the earth or in its atmosphere, we are limited to the SUN, to which all the magnetic phenomena have a distinct reference; but whether it acts by its heat or by its light, or by specific rays, or influences of a magnetic nature, must be left to future inquiry. Without placing any reliance on the observations which have been supposed to indicate a magnetic action in the violet rays, we attach some importance to the observations of Barlocci and Zantedeschi, who found that both natural and artificial magnets had their magnetism greatly increased by exposure to the common solar rays,—a result which could not arise from their heating power, as an increase of temperature invariably diminishes the power of magnets.

In the work of Dr Dalton, published in 1793, to which we have already referred, there are several ingenious hypothetical views respecting the cause of the aurora borealis and its magnetic influence, with which we were not acquainted till the sections on that subject were written; but as these views strongly confirm the hypothesis of terrestrial magnetism which we have ventured to bring forward, we shall state as briefly as we can the leading ideas of Dr Dalton.

1. *The region of the aurora* is 150 miles above the earth's surface. Immediately above the earth's surface is the region of the clouds, then the region of meteors called falling stars and fire-balls, and beyond this region

is that of the aurora. In proof of the great height of the aurora (independent of actual measurement) Dr Dalton adduces its extremely attenuated light, which, he says, may spread over one half of the hemisphere, and not yield more light than the full moon. "This," he continues, "arises from the extreme rarefaction of the air, which is almost tantamount to a Toricellian vacuum; in fact, the light of the aurora exactly corresponds with that of the electric spark when sent through a tube in which the air has been rarefied to as high a degree as can be effected by a good air-pump."

2. *The matter of the aurora.*—"From the conclusions in the preceding section," says Dr Dalton, "we are under the necessity of considering the *beams* of the *aurora borealis* of a *ferruginous* nature, because nothing else is known to be magnetic; and consequently that there exists in the higher region of the atmosphere an electric fluid, partaking of the properties of *iron*, or rather of *magnetic steel;* and that this fluid, doubtless from its magnetic property, assumes the form of cylindric beams." "My *fluid of magnetic matter,*" adds Dr Dalton in another place, "is, like magnetic steel, a substance possessed of the properties of magnetism." "Whether any of the various kinds of air or elastic vapour we are acquainted with is magnetic, I know not, but hope philosophers will avail themselves of these hints to make a trial of them."

3. *Exciting cause of the magnetism of the aurora.*—"With regard to the exciting cause of the aurora, I believe it will be found in change of temperature." "Nothing is known to affect the magnetism of steel; heat weakens or destroys it; electricity does more,—it sometimes changes the pole of one denomination to that of another, or inverts the magnetism. Hence we are obliged to have recourse to one of these two agents, in accounting for the mutations above mentioned. As for

heat, we should find it difficult, I believe, to assign a reason for such sudden and irregular productions of it in the higher regions of the atmosphere, without introducing electricity as an agent in these productions; but rather than make such a supposition, it would be more philosophical to suppose electricity to produce the effect on the magnetic matter *immediately*." "The beams of the *aurora* being magnetic, will have their magnetism weakened, destroyed, or inverted, *pro tempore*, by the several electric shocks they receive during an aurora."

4. *The nature of the magnetism of the beams of the aurora.*—Dr Dalton conceives the magnetism to be permanent, and not induced; and *each beam to be as it were a separate magnet*, with the regular polarity of permanent magnets. "I conceive that a beam may have its magnetism inverted, and exist so for a time, &c.; and I farther conceive, that when the beam is restored to its natural position of the north pole downward, it is effected, not by inverting the beam wholly as a beam, (for this is never observed in an aurora,) but by inverting the constituent particles, which may easily be admitted, of a fluid."

"If a magnet be required to be made of a given quantity of steel, it is found by experience to answer best when the length is to the breadth as 10 to 1 nearly. It is a remarkable circumstance, that the length and breadth of the magnetic beams of the aurora should be so nearly in that ratio. Query, If a fluid mass of magnetic matter, whether elastic or inelastic, were swimming in another fluid of equal density, and acted on by another magnet at a distance, what form would the magnetic matter assume? Is it not probable it would be that of a cylinder, of proportional dimensions to the beams of the *aurora*?"

5. *Governing cause of the magnetism of the aurora.*—"As the beams," says Dr Dalton, "are swimming in a

fluid of equal density with themselves, they are in the same predicament as a magnetic bar or needle swimming in a fluid of the same specific gravity with itself; but this last will only rest in *equilibrio* when in the direction of the *dipping needle*, owing to what is called the *earth's magnetism*; and as the former also rests in that position only, the effects being similar, we must, by the rules of philosophizing, ascribe them to the same cause. Hence then it follows, that THE AURORA BOREALIS IS A MAGNETIC PHENOMENON, AND ITS BEAMS ARE GOVERNED BY THE EARTH'S MAGNETISM." "I am aware that an objection may be stated to this; if the beams be swimming in a fluid of equal density, it will be said they ought to be drawn down by the action of the earth's magnetism. Upon this I may observe, that it is not my business to shew why this is not the case, because I propose the magnetism of the beams as a thing demonstrable, and not as a hypothesis. We are not to deny the cause of gravity because we cannot shew how the effect is produced. May not the difficulty be lessened by supposing the beams of less density than the surrounding fluid?"

Although this brief abstract of Dr Dalton's essay contains many views which in their general bearing add to the probability of the hypothesis which we have maintained, yet we must state in a few words the difference between the two hypotheses.

1. According to our views, terrestrial magnetism resides wholly in the earth's atmosphere, which contains throughout its whole extent ferruginous and other metallic matter, and sulphurous exhalations, all of which are carried up from the earth by evaporation, by ejection from volcanoes, and by the returning strokes of electricity from the earth to the air. The actual existence of such materials in the atmosphere, particularly sulphurous and ferruginous matter, is proved by the observations of

Fusinieri, and by the existence of meteoric stones and other solid substances which fall on the earth.

2. The magnetism which directs the needle is induced upon the magnetic matter in the atmosphere, like that of an iron sphere, by some exterior cause, although it is very probable that small local effects may be produced by ferruginous matter within the earth, and near its surface; but the only effect of these will be to produce small irregularities in the intensity of the magnetism of the needle, and in its direction.

3. As the colour of the electric spark, when taken from different bodies, or when passing through different media, depends on the solid matter which it renders luminous, so the different colours of lightning, of the auroral beams, of falling stars, and of meteors of every kind, are produced by the heat of the electric fluid either rendering the material substance visible by incandescence or throwing it into a state of combustion.

4. The beams of the aurora are those portions of the magnetic atmosphere through which electricity is passing, and which, by being heated to different degrees, are brought to different states of incandescence, and have their induced magnetism increased, like that of all ferruginous bodies which are brought to a temperature less than that of white heat.

Although it is universally admitted that a source of magnetism has been proved to exist in our atmosphere, and though it is evident that the force which emanates from it is greater than any magnetic force which can be proved to have its origin in the solid part of the earth, yet it may be asked if there is any reason for believing that the magnetism in the atmosphere is strong enough to be considered as the only source of terrestrial magnetism? To this question some of the facts already stated afford a pretty satisfactory answer. M. Arago has shewn that the auroræ which exist only at St Peters-

burg, in Siberia, and even in north America, actually disturb the magnetic needle at Paris; and he considers it highly probable that the auroras even round the south pole of our globe extend their influence to Paris. If a force of such magnitude exists in isulated beams which form regular magnets, according to Dr Dalton, we need not scruple to suppose that a ferruginous atmosphere is capable of producing that degree of intensity which characterizes terrestrial magnetism, and that the disturbances exhibited at Paris on the magnetic needle are the effect of local diminutions or augmentations of the magnetic force in Siberia, America, or even in the southern hemisphere.

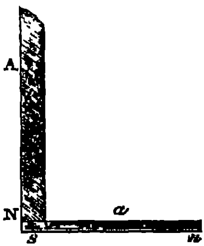
CHAPTER X.

ACCOUNT OF THE DIFFERENT METHODS OF MAKING ARTIFICIAL MAGNETS.

In the history of magnetism we have already made a brief reference to the principal methods of making artificial magnets. We shall now proceed to give a short account of the methods themselves.

In the infancy of the science, a bar B of hard steel was magnetized by rubbing it throughout its whole length on one of the poles N of a natural or artificial magnet A, in a direction at right angles to the line joining the two poles of the primitive magnet. By this process, the new bar *a* will be rendered slightly magnetic, but its magnetism cannot possibly be completely developed unless in the two cases where the new bar is extremely small, or the primitive magnet A extremely powerful; and the magnetism which is communicated often exhibits different poles, or consequent points as they are called, throughout the length of the new bar.

Fig. 60.



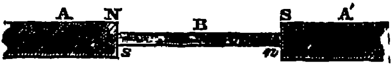
In using this method, the exciting pole should be slightly pressed upon the new bar; and after reaching the end of the bar at *s*, it must be lifted up and applied again to the other end, the friction being always made in the same direction.

Another old method of making magnets consisted in placing the end *s* of a new bar B *in contact* merely with one of the poles N of a powerful magnet, and striking the new bar so as to make it ring during the time of its application. This method, however, like the first, will be effectual only for very small bars; the pole *s* will be the strongest, and the neutral point at B will be nearer *s* than *n*.

Fig. 61.

A more efficacious method of magnetizing small bars by simple contact, is shewn in the annexed figure, by placing the new bar B between the opposite poles N, S, of two strong magnetic bars A, A′, of nearly equal power. In this case the magnetism of B will be nearly twice as great as when only one, B or A, is used; and if there are no consecutive poles produced, the neutral point B will bisect *ns*.

Fig. 62.



These simple methods were discontinued when the principles of magnetic induction were better understood, and several ingenious and highly effective processes of making artificial magnets were invented by the philosophers of the eighteenth century. The first of these was that of Mr Knight.

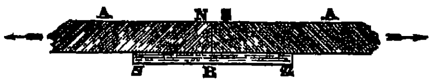
SECT. I.—*Account of Dr Gowin Knight's method of making Artificial Magnets.*

Dr Gowin Knight, a physician in London, was long celebrated for the excellence of the artificial magnets which he made. The method which he used was kept a

secret during his life, but was published after his death by Mr Wilson.

The bar or needle B, which he intended to magnetize, was tempered at a *cherry-red heat*, and placed under the

Fig. 63.



opposite poles N S of two equal magnets. These magnets are then separated in opposite directions S A′, N A, so that the south pole S of the one passes over the *north polar* half B*n* of the bar B, and the north pole N of the other over the *south polar* half B *s* of B. This operation is repeated several times, till the magnetism of the bar B is fully developed.

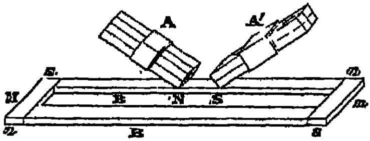
In this process the north pole N, while it attracts to the half B *n* all the south polar magnetism in B *s*, repels at the same time into B*s* all the north polar magnetism of B *n*. The same is true, *mutatis mutandis*, with the south pole S. When the bars A A′ are large and powerful, it has been found that this process is capable of communicating to small bars all the magnetism of which they are susceptible.

SECT. II.—*Account of Duhamel's method of making Artificial Magnets.*

After Dr Knight's process had been known and used, the artificial magnets which were made by it were in great

request, and distributed throughout Europe. When the process, however, was applied to bars of great size, it was found to be defective; and M. Duhamel of the Academy of Sciences, in conjunction with M. Antheaume, set

Fig. 64.

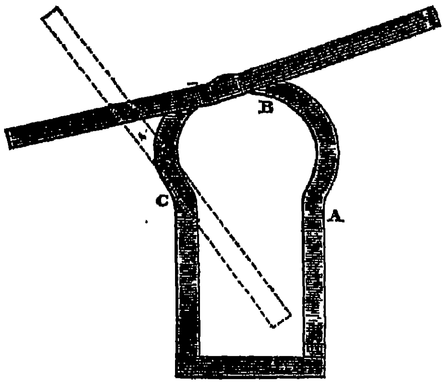


themselves to devise a better method, which is represented in the annexed figure. The bars B B′ to be magnetized are placed parallel to each other, and have their extremities united by two pieces M *m* of soft iron, at right angles to the bars. He then took two strong magnets A A′, or two bundles of small bar-magnets, the bars of each bundle having their similar poles together; and having placed them, as in the figure, at an angle of about 90°, or inclined 45° to the bar B, they were separated from each other as already described in the explanation of fig. 63. The same operation was repeated on the other bar B′, and continued alternately on both till the magnetism was supposed to be completely developed in both bars. When A and A′ are placed upon the second bar B′, the disposition of the poles must be reversed, the pole that was formerly to the right hand being now placed to the left. The two bars B B′ are then turned, so that the undermost faces are uppermost, and the same process carried on as before.

The distinctive peculiarity of Duhamel's process consists in the employment of the pieces of iron M *m*, and in the use of bundles of small bars, which are more efficacious than two single ones of the same size.

The very same method is applicable to curved bars, or those of the horse-shoe form, as shown in the annexed figure, where the inclined bars are carried round the

Fig. 65.

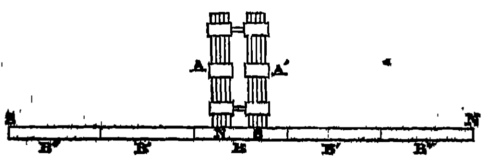


curved bar A B C, exactly as they were along the straight bar B.

SECT. III.—*Account of Mr Michell's method of making Artificial Magnets.*

About the same time that Duhamel was occupied with this subject, Mr Michell of Cambridge and Mr Canton were separately engaged in the same inquiry. Mr Michell published his method in 1750, to which he gave

Fig. 66.



the name of the *method of double touch*. Having joined together, at the distance of a quarter of an inch, two bundles of strongly magnetized bars A A′, their opposite

poles N S being together, he placed five or more equal steel bars B B′ B′ B″ B″ in the same straight line; and resting the extremity of the bundle of magnets A A′ upon the middle of the central bar B, he moved them *backwards* and *forwards* throughout the whole length of the line of bars, repeating the operation on each side of the bars, till the greatest possible effect was produced. By this method Mr Michell found that the middle steel bars B B′ B′ acquired a very high degree of magnetic virtue, and greater than the outer bars B″ B″; but by placing these last bars in the middle of the series, and repeating the operation, they acquired the same degree of magnetism as the rest.

Mr Michell states, that two magnets will, by his process of double touch, communicate as strong a magnetic virtue to a steel bar, as a single magnet of five times the strength, when used in the process of single touch. The bars A A′ act with the sum of their powers in developing magnetism in all parts of the line of bars between them, and with the difference of their powers in all parts of the line of bars beyond them. The external bars act the same part in this process as the two pieces of soft iron in the method of Duhamel.

SECT. IV. — *Account of Canton's method of making Artificial Magnets.*

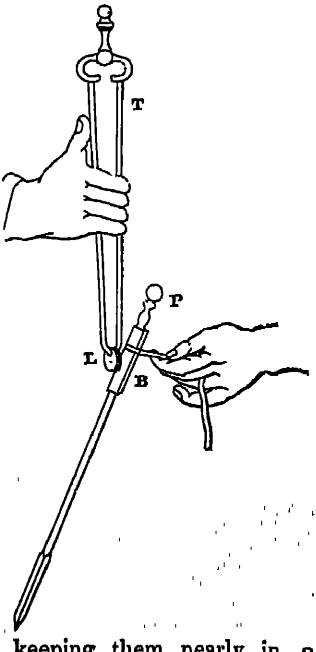
In the year 1751 Mr Canton published his process, which he regarded as superior to preceding ones. He placed the bars as in Duhamel's method, joined by pieces of soft iron. He then applied Michell's method of double touch, and afterwards he separated the two bundles of magnets A, A′, and having inclined them to each other, as in Duhamel's method, he made them rub upon the bar from the middle to its extremities. The peculiarity of

Canton's method is the union of these two processes ; but Coulomb and others are of opinion that the latter part of the process is the only effectual one.

In order to make artificial magnets without the aid either of natural loadstones or artificial magnets, Mr Canton gives the following detailed process.

He takes six bars of soft and six of hard steel, the former being smaller than the latter. The bars of *soft* steel should be three inches long, one-fourth of an inch broad, and one-twentieth thick; and two pieces of iron must be provided, each having half the length of one of the bars, and the same breadth and thickness. The bars of *hard* steel should be each five and a half inches long, half an inch broad, and three-twentieths of an inch thick, with two pieces of iron of half the length, and the same breadth and thickness.

Fig. 67.

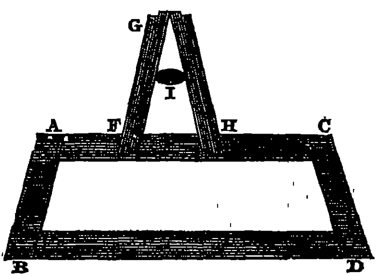


All the bars being marked with a line quite round them at one end, take an iron poker and tongs, or two bars of iron, the larger and the older the better, and fixing the poker P upright, as in fig. 67, hold to it with the left hand, near the top P, by a silk thread, one of the *soft* bars B, having its marked end downwards; then grasping the tongs T with the right hand, a little below their middle, and keeping them nearly in a

vertical line, let the bar B be rubbed with the lower end L of the tongs, from the marked end of the bar to its upper end, about ten times on each side of it. By this means the bar B will receive as much magnetism as will enable it to lift a small key at the marked end; and this end of the bar being suspended by its middle, or made to rest on a point, will turn to the *north*, and is called its *north* pole, the unmarked end being the *south* pole.

When four of the soft steel bars are thus rendered magnetic, the other two AC, BD, must be laid parallel to each other, at the distance of about one fourth of an inch, as in the figure, having their dissimilar poles united with the smallest pieces of iron A B, C D. Two of the magnetized bars are then to be placed together, as at G, with their similar poles united, and the other two as at K; and when separated by a piece of wood I, they are slid four or five times backwards and forwards along the whole length of the bar AC, so that the marked end F of G is nearest the unmarked end of AC, and *vice versa*. This operation is carefully repeated on BD, and on the other sides of both AC and BD. When this is done, the bars AC, BD are to be taken up and substituted for the two outer bars of the bundles G, K, these last being laid down in the place of the former, and magnetized in a similar manner. This operation must be repeated till each pair of the soft bars has been magnetized *three* or *four times*.

Fig. 68.

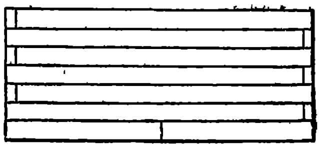


When the six soft bars are thus magnetized, they must

be formed into two bundles of three each, with their similar poles together, and must be used to magnetize two of the *hard* bars in the manner already described; and when they are magnetized, other two of the hard bars must be touched in a similar manner. The soft bars are now to be laid aside, and the remaining two hard bars magnetized by the *four* hard bars already rendered magnetic; and when this is done the operation should be repeated by interchanging the hard bars, till they are impregnated with the greatest degree of permanent magnetism which this method is capable of communicating to them.

In performing the above operations, which may be completed in about half an hour, the bars AC, BD, and the pieces AB, CD, should be placed in grooves, or fixed between pins of wood or brass, to keep them steady during the successive frictions which are applied to them. According to Canton, each of the six artificial magnets thus made will lift about twenty-eight ounces troy. They should be kept in a wooden box, and placed as in the annexed figure, so that no two poles of the same name may be together, and the pieces of iron A B, C D, placed beside them.

Fig. 69.



SECT. V.—*Account of Æpinus's method of making Artificial Magnets.*

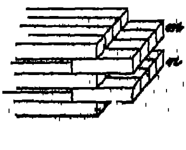
The method of magnetizing steel bars by the double touch was greatly improved by Æpinus. In place of the pieces of iron M, *m*, used by Duhamel, he used magnets, and formed the rectangle with the two steel bars to be magnetized, having their extremities united by two

magnets M, *m*, placed as in figure 64. He then placed the original magnet, or bundles of magnets, A, A′, as in the figure, having their dissimilar poles N S separated by a piece of wood, and greatly inclined to each other; and he made the united poles pass backwards along the whole length of the steel bar. The same operation was repeated on the other bar, and on the other side of each of them, care being taken to reverse the poles, as formerly mentioned, when the rubbing bars are removed from the one steel bar to the other. Æpinus found that a maximum effect was produced when the bars A A′ were inclined 20° or 30° to the steel bar over which they passed.

Sect. VI.—*Account of Coulomb's method of making Artificial Magnets.*

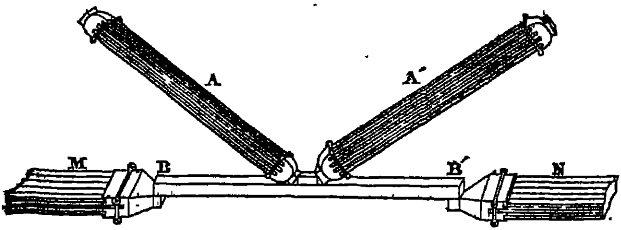
The method of making artificial magnets employed by Coulomb consists of the most efficacious parts of the preceding processes, improved and extended by long experience in the art. The apparatus which he uses consists of *fixed* and *moving* bundles of magnets. Each of the fixed bundles consists of *ten* bars of steel tempered at a cherry-red heat, their length being about twenty-one inches, their breadth six-tenths of an inch, and their thickness one-fifth of an inch. Having rendered them as strongly magnetic as possible, with a natural or an artificial magnet, he joined them with their similar poles together, and formed them into two beds of four bars each, these beds being separated by small rectangular parallelopipeds *m n* of soft iron, projecting a little beyond their extremities, as shewn in the annexed figure. The *moving* bundles consist of four bars

Fig. 70.



tempered at a cherry-red heat, each being about sixteen inches long, six-tenths of an inch wide, and two-tenths of an inch thick. When these bars were magnetized in the same manner as the other bars, he united two of them by their widths and two of them by their thickness, so that each bundle was one inch and two-tenths wide and four-tenths thick, the bars being separated, as before, by pieces of soft iron. Coulomb used a kind of steel very common in commerce (*d'acier timbré à 7 étoiles*;) but he found that all kinds, provided it was no of a bad quality, were capable of receiving the same degree of magnetism. In order to magnetize a bar, he

Fig. 71.



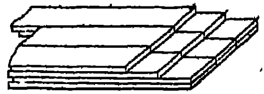
placed the large fixed bundles M N in the same straight line, and at a distance a little less than the length of the bar to be magnetized; and this bar BB′ was placed as in the figure, so as to rest on the projecting pieces of iron, so that the contact took place only over a length of one-fifth of an inch; the two moving bundles A A′ having their dissimilar poles separated by a small piece of wood or copper, about one-fifth of an inch wide between them, and each being inclined at an angle of 20° or 30° to the bar BB′. The united poles of the moving bundles are then moved successively from the centre to each extremity of the bar BB′, so that the number of frictions upon each half of the bar may be equal. When the last friction has been given, the united poles are brought to the

middle point of the bar BB′, and then withdrawn perpendicularly. The same operation is then repeated on the other side of the bar BB′. If we wish to employ the method of Duhamel in place of that of Æpinus, we do not require the piece of wood or copper, but have only to separate the bars when their united poles are in the middle of the bar BB′, making each pole pass to the extremity of it.

When the fixed and moving bundles are composed of bars which have not been magnetized to saturation, we must form new bundles with the newly magnetized bars, whose magnetism will be stronger than those by which they were magnetized, and by their heat magnetize anew the bars first used; and by repeating this process three or four times, the bars may be raised to the highest degree of magnetic virtue.

When the bars BB′ to be magnetized are very large, the moveable bundle should contain more than four bars, each of the bars retreating about half an inch in the direction of their thickness, as shewn in the annexed figure. The advantage of this displacement arises from the fact, that the highest degree of magnetism resides in the extremity of the bar. Hence, by this arrangement, not only the most efficacious parts of the moving bar are brought into contact with the bar to be magnetized, and act more powerfully, but the bar nearest to the central one in the bundle tends not merely to maintain, but to augment, in its extremity, its degree of magnetism. The third bar produces the same good effect upon the second, and so on with the rest.

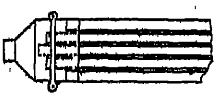
Fig. 72.



SECT. VII.—*Account of M. Biot's method of making Artificial Magnets.*

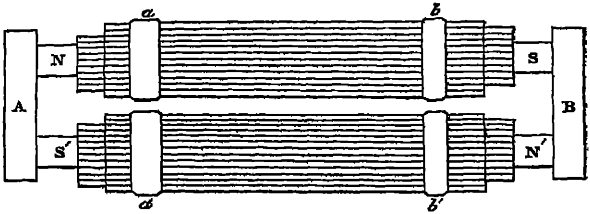
M. Biot has proposed several important improvements on the process of Coulomb. As the bars are always bent a little in tempering, he recommends that they should at first be brought to as hard a temper as possible, and then annealed to the first shade of yellow. By this means they will have a sufficient degree of malleability to be again brought into shape, while they possess sufficient coercive power for receiving and retaining a high degree of magnetism. Regarding it as of essential importance to ensure an intimate contact between the plates of the large bundles and the soft iron or armour by which they are united, M. Biot forms his armour of several plates of very soft iron, which cover the elementary plates at that part of their extremities where the repartition of free magnetism is perceptible. These plates of soft iron form part of a mass of the same nature terminating in the form of a trapezoid, as shewn in the annexed figure, and the plates of steel are inserted in it, as shewn by the dotted lines; so that the plates which lie in the axis of the bundles project a little beyond the lateral plates. The whole is then bound together with a collet of soft iron, held firmly by a screw. M. Biot remarks, that he has found from experience that this arrangement, indicated by theoretical considerations, is extremely advantageous.

Fig. 73.



Coulomb's method of fitting up, arming, and preserving his magnets, is shewn in the annexed figure, representing two artificial magnets, armed at their extremities with

Fig. 74.



two iron parallelopipeds, N S, N′ S′; N N′ being the north poles, and S S′ the south poles. These parallelopipeds have their inner ends enveloped within the magnetic bars. The opposite poles N S′, N′ S, are joined by pieces of soft iron A B, and the bars of each magnet are held together by the upper bands *a b*, *a′ b′*.

With an apparatus of this kind, each part weighing fifteen or twenty pounds, eighty or a hundred pounds is required to separate the pieces A B from the poles, and an ordinary needle is magnetized to saturation by merely placing it upon the ends N S′ or N′ S.

Sect. VIII.—*Account of Mr Scoresby's method of making Artificial Magnets.*

A very simple and efficacious method of making artificial magnets by percussion has been published by Mr Scoresby.* That iron became magnetic when struck by successive blows of a hammer in the direction of the dipping needle, was known to Dr Gilbert; but it is to Mr Scoresby that we owe a complete investigation of the subject. In order to determine the effects produced by percussion, Mr Scoresby used two methods, the one by observing the weight which the new magnet lifted, and the other by measuring the deviation which it produced on

* *Philosophical Transactions*, 1822, part ii. p. 241.

a magnetic needle. The following experiments were made with a cylindrical bar of soft steel six and a half inches long, one fourth of an inch in diameter, and weighing 592 grains. It was placed in a vertical position, resting on a piece of tin, and struck with a hammer of twelve ounces.

Number of Strokes at each Experiment.	Total Number.	Weight suspended by the Bar.	Deviation of the Needle; distance of Needle three Inches.
1	1	2	8°
1	2	0	10
5	7	4	12
10	17	6½	12½
5	22	6½	12½

When the steel bar was placed upon a stone, the effect was the same; but, as the following experiments shew, a great increase of power was obtained by supporting the lower end of the bar upon the upper end of a large bar of iron or soft steel. The hammer weighed twelve ounces, and the distance of the needle was three inches.

Number of Strokes at each Experiment.	Total Number.	Weight suspended by the Bar.	Deviation of the Needle.
1	1	6½ grs.	13°
1	2	14	16
1	3	—	18
4	7	37	21
5	12	45	25
10	22	88	27
20	42	88	30
30	72	—	31
10	82	—	31½

Number of Strokes at each Experiment.	Total Number.	Weight suspended by the Bar.	Deviation of the Needle.
By using a hammer weighing 22 ounces, an increased effect was produced.			
3	85	—	33
5	90	130	34
3	93	—	30
By reversing the poles, and again hammering with the twelve-ounce hammer.			
1	—	—	5
1	2	—	2

From these experiments it follows, that a cylindrical bar of soft steel weighing 592 grains, can be made to lift only six and a half grains when struck in a vertical position, with its lower end resting upon tin or stone; whereas the same bar, when struck with twenty-two blows upon a rod of iron suspended at its lower end, which was a north pole, lifted eighty-eight grains; by using a larger hammer, its lifting power increased to 130. When the steel bar was reversed, so that its south pole was uppermost, its magnetism was almost destroyed by a single blow, and two blows were sufficient to change its poles. Mr Scoresby found that when the steel magnet was struck in the plane of the magnetic equator, its polarity also disappeared; but several blows were necessary to effect this change.

In another set of experiments on the effect of percussion on magnets, he employed a flat bar-magnet seven and seven-tenths inches long, half an inch wide, one-seventh thick, and weighing 1170 grains.

When suspended vertically, with its south end uppermost, it produced, at the distance of eight inches, a deviation of 45° on the needle; but after 60, 80, and 100 blows, the deviation was reduced to 25°.

When the north pole was placed uppermost, other thirty blows reduced the deviation still farther, from 25° to 14°.

When the bar was again magnetized, and hammered, upon a piece of tin, it produced a deviation of 50°; but after twenty blows, with the south pole uppermost, the deviation became 33°. By other sixty blows, with the north pole uppermost, the deviation became 24°.

From the results obtained in the preceding experiments, Mr Scoresby deduced the following method of making artificial magnets by percussion.

"I procured two bars of soft steel thirty inches long and an inch broad, also six other flat bars of soft steel eight inches long and half an inch broad, and a large bar of soft iron. The large steel and iron bars were not, however, absolutely necessary, as common pokers answer the purpose very well; but I was desirous to accelerate the process by the use of substances capable of aiding the development of the magnetical properties in steel. The large iron bar was first hammered in a vertical position; it was then laid on the ground with its acquired south pole towards the south, and upon this end of it the large steel bars were rested while they were hammered; they were also hammered upon each other. On the summit of one of the large steel bars, each of the small bars, held also vertically, was hammered in succession, and in a few minutes they had all acquired considerable lifting powers. Two of the smaller bars, connected by two short pieces of soft iron in the form of a parallelogram, were now rubbed with the other four bars, in the manner of Canton. These were then changed for two others, and these again for the last two. After treating each pair of bars in this way for a number of times, and changing them whenever the manipulations had been continued for about a minute, the whole of the bars were

at length found to be magnetized to saturation, each pair readily lifting above eight ounces.

"In accomplishing this object, I took particular care that no magnetic substance was used in the process. All the bars were freed of magnetism before the experiment, so that none of them, not even the largest, produced a deviation of five degrees on the compass at three inches distance. Any bars which had been strongly magnetized, and had their magnetism destroyed or neutralized (either by hammering, heating, or by the simultaneous contact of the two poles of another magnet placed transversely,) I always found had a much greater facility for receiving polarity in the same direction as before, than the contrary. Hence it generally happened that one blow with the original north end downwards, produced as much effect as two or three blows did with the original south end downwards."

By this ingenious process, any person who has no magnets within his reach may communicate the strongest degree of permanent magnetism to hard steel bars of any magnitude, the bars magnetized by percussion being employed, as in the process of Coulomb, to magnetize the large bars which are required.

SECT. IX. — *Method of making Horse-Shoe Magnets.*

Horse-shoe magnets are those which have the form of a horse shoe, as shewn in fig. 65; and this form is, generally speaking, the most convenient for use, and for the preservation of their magnetic power. In all experiments where a large weight is to be lifted, the horse-shoe magnet is indispensable; and in consequence of the two poles being brought together, they may be substituted with great advantage for magnetizing steel bars by the method of double touch.

In order to form a powerful magnetic battery, the best way is to unite a number of similar horse-shoe magnets, with their similar poles together, and to fix them firmly together in a case of copper or leather. The following is the method recommended and used by Professor Barlow: He took bars of steel twelve inches long, and having bent them into the horse-shoe shape, their length was six inches, their breadth one inch at the curved part, and three-fourths of an inch at their extremities, and their thickness one-fourth of an inch. They were filed very nicely, so as to correspond, and lie flatly upon each other. They were then drilled with three holes in each, as seen in the figure, and, by means of screws V V passing through these holes, *nine* horse-shoe bars were bound together. When the heads and ends of the screws were constructed, so as to leave the outer surfaces smooth, the mass of bars was filed as if they were one piece, and the surface made flat and smooth. When the bars were separated, they were carefully hardened, so as not to warp; and when they had been well cleaned, and rendered bright, but not polished, they were magnetized separately in the following manner: When the two extremities of the bar are connected by a piece of soft iron M, the magnetism may be developed in the two halves by Duhamel's method, as in the annexed figure; or, following Æpinus, we may apply a strong magnet to each pole, and connect their extremities either with a piece of soft iron or another magnet, or we may apply two horse-shoe

Fig. 75.

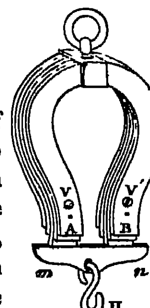
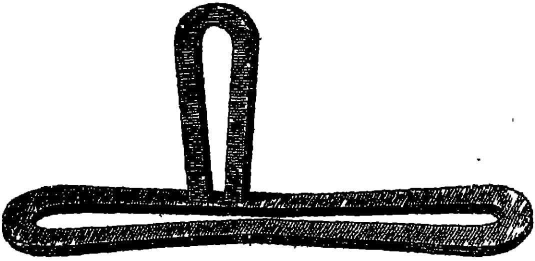


Fig. 76.

magnets to each other, as in the annexed figure, uniting the poles which are to be of contrary names. When the

Fig. 77.



magnet or magnets are prepared in any of these ways, they are then to be magnetized with another horse-shoe magnet AB, by placing its north pole next to what is to be the south pole of one of the horse-shoe bars, and then carrying the moveable magnet round and round, but always in the same direction. In this way a very high degree of magnetic virtue may be communicated to each of the *nine* bars. When this is done, they are to be reunited by the three screws, and their poles or extremities connected by a piece of soft iron, or *lifter*, as in fig. 75, having at its middle a hook H for suspending any weight. As the lifting power depends on the accurate contact of the poles of the magnets with the lifter, the extremities should, after hardening, be properly rubbed down with putty upon a flat surface.

A magnet of this size and form was found by Professor Barlow to suspend *forty pounds*; but he afterwards found that a greater proportional power could be obtained by using bars that were long in comparison with their breadth.

Sect. X.—*Account of Professor Barlow's method of magnetizing a number of Rectilineal Bars with a Horse-Shoe Magnet.*

The following method of making artificial magnets is both a simple and efficacious one, and has been practised successfully by Professor Barlow. Having occasion for thirty-six magnets, twelve inches long, one and a fourth broad, and seven-sixteenths of an inch thick, he placed thirty-six bars of steel, of these dimensions, on a table, so as to form a square, having nine bars on each side, the marked or north pole of each bar being in contact with the unmarked or south pole. At the angular points of the square the inner edges of the bars were brought into contact, and the external opening thus left was filled up by a piece of iron one inch and a quarter square and seven-sixteenths of an inch thick. The horse-shoe magnet described in the preceding section was set upon one of the bars, so that its north pole was towards the unmarked end of the bar, and was then carried or rubbed along the four sides of the bars; and the operation was continued till the horse-shoe magnet had gone twelve times round the square. Without removing the magnet, each bar was turned one by one, so as to turn their lower sides uppermost, and the horse-shoe magnet was made to rub along the four sides of the square other twelve times. The bars were then highly magnetized; and the whole process did not occupy more than half an hour.

Sect. XI.—*Account of Knight's method of forming Artificial Magnets with an Iron Paste.*

Although the following method of making a magnetic paste has been given in almost every treatise on magnetism,

and was kept a secret by its inventor, yet we have no distinct information that it has been found superior in any respect to steel as a vehicle of magnetism. Mr Benjamin Wilson communicated the method to the Royal Society after the death of Mr Knight.

"Having provided himself with a large quantity of clean filings of iron, Dr Knight put them into a tub that was more than one-third full of clean water; he then, with great labour, worked the filings to and fro for many hours together, that the friction between the filings of iron by this treatment might break off such small parts as would remain suspended in the water for some time; the obtaining of which very small particles in sufficient quantity seemed to him to be one of the principal desiderata in the experiment. The water being by this treatment rendered very muddy, he poured it into a clean earthen vessel, leaving the filings behind; and when the water had stood long enough to become clean, he poured it out carefully, without disturbing such of the iron sediment as still remained, which was now reduced to an almost impalpable powder. This powder was afterwards removed into another vessel, in order to dry it; but as he had not obtained a proper quantity of it by this first step, he was obliged to repeat the process many times. Having at last procured enough of this very fine powder, the next thing to be done was to make a paste of it, and that with some vehicle which could contain a considerable quantity of the phlogistic principle. For this purpose he had recourse to linseed oil in preference to all other fluids. With these two ingredients only he made a stiff paste, taking particular care to knead it well before he moulded it into convenient shapes. Sometimes, while the paste continued in its soft state, he would put the impression of a seal on several pieces, one of which is in the British Museum. This paste was then put upon wood, and sometimes on tiles, in order to bake or dry it

before a moderate fire, at about a foot distance. The doctor found that a moderate fire was most proper, because a greater degree of heat made the composition frequently crack in many places.

"The time necessary for baking this paste was generally five or six hours before it attained a sufficient degree of hardness. When that was done, and the several baked pieces were become cold, he gave them their magnetic virtue in any direction he pleased, by placing them between the extreme ends of his magazine of artificial magnets, for a few seconds or more, as he saw occasion. By this method the virtue they acquired was such, that when any one of these pieces was held between any of his best ten-guinea bars, with its poles purposely inverted, it immediately of itself turned about to recover its natural direction, which the force of these very powerful bars was not sufficient to counteract."* After giving the preceding method, M. Biot remarks that it consists in procuring a very fine powder of iron a little oxidated, all the particles of which he united by means of linseed oil, or any other substance fitted to give them a proper degree of oxygenation. "When this paste was magnetized," he continues, "each particle of the powder became a small magnet, in which the development of the magnetism might be very powerful, on account of the suitable degree of coercive power produced by the oxygenation; and the homogeneity of this state in all the particles, as well as their extreme tenuity, might give to the whole system the most favourable arrangements for receiving a high degree of magnetism." M. Biot conceives that a somewhat analogous effect might be obtained by steel of an equal and homogeneous grain, the carbon giving a coercive power like oxygen; but he thinks that the paste is likely to form better magnets. He is of opinion also

* *Phil. Trans.* 1779, vol. lxix. p. 51.

that some powerful natural magnets may owe their virtue to the union of similar qualities.

Dr Fothergill, who had seen Mr Knight's paste magnets in his own possession, says that the mass had the appearance of a piece of black lead, though less shining. He informs us also of a very remarkable fact, if it be true, that while the poles of a natural loadstone, or of the hardest steel magnet, could be changed, those of the paste magnets were immoveable. A small piece, of about half an inch square and one-fourth thick, was powerfully magnetic, though unarmed; and its poles could not be altered though it was placed between two of Mr Knight's largest and most strongly impregnated magnetic bars.*

Conceiving that the powder which formed the basis of this paste was the *black oxide of iron*, or *martial Ethiops*, M. Cavallo has given the following receipt for imitating natural magnets; but he does not say that the magnets made by it are better than those of steel. "Take some martial Ethiops reduced into a very fine powder, or, which is more easily procured, *black oxide of iron*, the scales which fall from red-hot iron when hammered, and are found abundantly in smiths' shops. Mix this powder with drying linseed oil, so as to form it into a very stiff paste, and shape it in a mould so as to give it any form you require, whether of a terrella, a human head, or any other. This done, put it into a warm place for some weeks, and it will dry so as to become very hard; then render it magnetic by the application of powerful magnets, and it will acquire a *considerable* power."

SECT. XII.—*Account of the method of arming and preserving Natural and Artificial Magnets.*

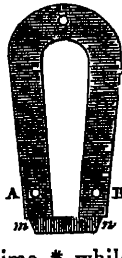
We have already stated, that when a piece of soft iron is suspended at the pole of a magnet, this piece of iron is

* *Phil. Trans.* 1779, vol. lxvi.

rendered magnetic, and that a second and a third smaller piece of iron suspended from the other piece of iron also become magnetic, the magnet developing magnetism in the first piece of iron, the first piece developing it in the second, and so on. Each piece of iron re-acts as a magnet on the larger piece on which it hangs, improving or increasing the development of its magnetism. Hence the lifting power of a magnet may be increased by suspending to one of its poles, day after day, a small additional piece of iron.

On this property is founded the method of arming natural and artificial magnets, for the purpose both of increasing and preserving their magnetic power. In order to support the greatest weight with any magnet, both its poles should be brought in action. In the horse-shoe magnet this is easily done, so that the *armature* for it is made by merely placing a piece of soft iron *mn* upon its poles A (north,) B (south,) having a hook attached to it for hanging on weights, as in fig. 75. That the power of this magnet is not only increased, but preserved, is easily proved; but the following striking experiment of Mr Watkins affords the most beautiful illustration of the principle. He magnetized a horse-shoe bar *of soft iron*, made of a bar nineteen inches long and one inch square, when its poles A B were joined by another piece of iron *m n*, and he found that it preserved its magnetic virtue for a long time,* while its poles were thus united. The moment, however, that the armature *mn* was removed, the magnetism of the horse-shoe bar almost wholly disappeared.†

Fig. 78.



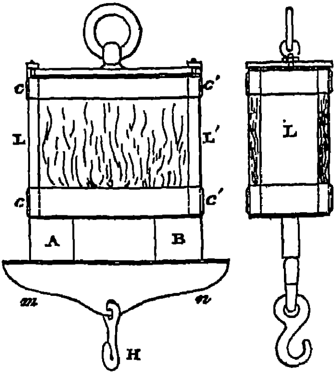
The best armature for a natural magnet is shewn in the

* See the following section.

† *Phil. Trans.* 1838, p. 388.

annexed figure, where L L′ are two broad pieces of soft iron applied to the poles, and projecting on one side of it. To these projecting ends or transferred poles A B a piece of iron *m n* is applied, so as to touch them both, as in the horse-shoe magnet in fig. 75. The lateral pieces of iron L L′ are commonly held firm to the magnet by means of a box of brass, silver, or copper, *ccc′c′*, and the magnet is then said to be armed, the pieces of iron L L′, A B, constituting its arms or armature.

Fig. 79.



A loadstone armed in the preceding manner may be strengthened by Professor Barlow's method of magnetizing horse-shoe magnets; and if we suspend a scale or bag from the hook H, and add, day after day, some additional weight, it may be made to suspend *two* or *three* times the weight that it could lift if applied to it at once. If its force, however, is overpowered by too great a load, its strength will revert to what it was at first; but if we take out of the scale a certain part of the load which it can suspend, we may again proceed to add more weight gradually, till it carries its maximum load.

In order to preserve loadstones and magnets, their armature should always be applied to them. They should be kept in a cool place, free from vibrations, and rough treatment of every kind. Bar-magnets should always be kept with their dissimilar poles together; and both single magnets and needles will have their power not only pre-

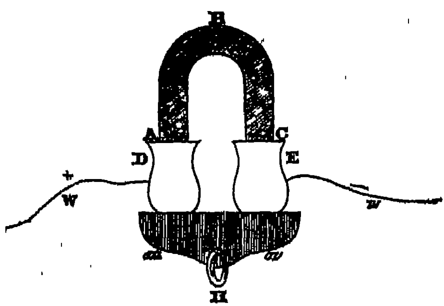
served, but increased, by keeping them surrounded with a mass of dry filings of soft iron, each particle of which will re-act, by its induced magnetism, upon the point of the magnet to which it adheres, and maintain in that point its primitive magnetic state.

SECT. XIII.—*Account of the method of making Temporary Bar-Magnets of Soft Iron under the influence of Electric Currents.*

In our history of ELECTRICITY we have given some account of the discoveries of M. Arago, Sir H. Davy, M. Savary, and others, relative to the communication of magnetism to steel by ordinary electricity. The subject will be resumed under the article VOLTAIC ELECTRICITY; but, without anticipating what properly belongs to that science, we shall give an account in this section of the method of making bar-magnets of soft iron by the influence of electric currents.

This process consists in winding spirally round a horse-

Fig. 80.



shoe bar of iron ABC, a copper wire covered with silk thread. A galvanic current is then made to pass through

the bar ABC, by two wires W *w*, communicating with two wooden vessels D E containing mercury. When the voltaic apparatus consists of a single element, viz. one plate of zinc placed in a copper vessel, and having an area of five square feet, the magnet, when armed, as shewn at *mn*, may suspend by the hook H 100 killogrammes.

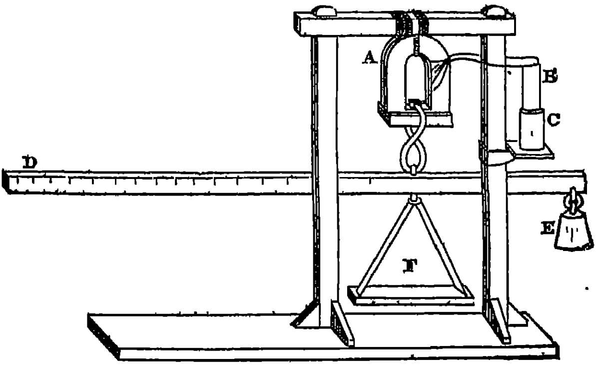
Dr Moll* took a horse-shoe bar 0·22 of a metre high, and 0·025 thick, and rolled round it eighty-three times a copper wire covered with silk, and 0·003 of a metre in diameter. To each of the branches was adapted a counterweight of a pound weight, and projecting a little on both sides. The two extremities of the wire were made to communicate, by small vessels of wood filled with mercury, with two elements of a voltaic battery, composed of a bucket of copper, in which was plunged a plate of zinc whose surface, in contact with the fluid, was eleven square feet. The moment the communication was made, the magnet supported twenty-five killogrammes, and with some precautions thirty-eight. Another horse-shoe bar, weighing thirteen killogrammes, 0·93 of a metre high, and fifty-five millimetres thick, lifted seventy-seven killogrammes. When the direction of the current is changed, the poles of the magnet are instantly reversed; and when the current is stopped the magnetism of the bar diminishes, though Dr Moll found it capable of carrying twenty-five killogrammes a quarter of an hour after the current ceased. Dr Moll found that the magnetic intensity of the bar was not increased by increasing the number of the voltaic elements or plates; that a horse-shoe of copper was not magnetized; and that a horse-shoe magnet was not rendered more magnetic by the electric current.

Professor Henry of Albany Academy had obtained analogous results about the same time with Professor

* *Ann. de Chim.* vol. l. p. 326.

Moll. The apparatus which he used is shewn in the annexed figure, which represents a strong rectangular

Fig. 81.



wooden frame, three feet nine inches high, and twenty inches wide. The magnet A is covered with linen, and the ends of the wires coiled round it, all project so as to be soldered to the galvanic element B, which can be plunged into the vessel C placed on a moveable shelf, and containing dilute acid. D is a graduated lever, E a counterpoise, and F a scale for supporting weights, when the lifting power is not estimated by a small weight sliding upon the lever. The magnet A was fitted up in the following manner. "A bar of soft iron two inches square and twenty inches long was bent into the form of a horse-shoe nine inches and a half high; the sharp edges of the bar were first a little rounded with a hammer; it weighed twenty-one pounds. A piece of iron from the same bar, weighing seven pounds, was filed perfectly flat on one surface, for an armature or lifter; the extremities of the legs of the horse-shoe were also truly ground to the surface of the armature. Around this horse-shoe 540 feet of copper bell-wire were wound,

in nine coils of sixty feet each. These coils were not continued around the whole length of the bar, but each strand of wire, according to the principle before mentioned, occupied about two inches, and was coiled several times backward and forward over itself; the several ends of the wires were left projecting, and all numbered, so that the first and the last end of each strand might be readily distinguished. In this manner was formed an experimental magnet on a large scale, with which several combinations of wire could be made by merely uniting the different projecting ends. Thus, if the second end of the first wire be soldered to the first end of the second wire, and so on through all the series, the whole will form a continued coil of one long wire. By soldering different ends, the whole may be formed into a double coil of half the length, or into a triple coil of one third the length," &c.*

In making experiments with this magnet, a small single battery was used, consisting of two concentric copper cylinders, with zinc between them; the whole of the zinc surface in action, including both sides of the zinc, was two-fifths of a square foot, and the quantity of dilute acid only half a pint. The following were the results: —

Number of Wires soldered to the Battery in succession.		Weight lifted in Pounds avoirdupois.
1.	Each soldered to the battery in succession	7
2.	One on each side of the arch	145
2.	One from each end of legs	200
3.	One from each end of legs, and the other from middle of arch	300
4.	Two from each end	507

* Professor Silliman's *Journal*, 1831, vol. xix., p. 404.

Number of Wires soldered to the Battery in succession.		Weight lifted in Pounds avoirdupois.
6.	Wires attached..	570
9.	All the wires attached..................................	650
9.	A plate of twelve inches long and six wide, and surrounded with copper, substituted for the preceding battery........................	750

When a pair of plates, exactly *one inch square*, was attached to the wires, the weight lifted was eighty-five pounds.

Professor Henry mentions that this magnet weighed twenty-one pounds, and lifted more than thirty-five times its own weight, whereas the largest natural magnet known, and in the possession of Mr Peale of Philadelphia, lifts three hundred and ten pounds, or about six times its own weight.

MM. Lipkens and Quetelet found that great effects will be produced by small voltaic surfaces, provided that the chemical action is energetic, and that the degree of magnetism depends more on the size of the iron shoe, than on the dimensions of the voltaic plates.*

The horse-shoe iron magnets formed by electrical currents are only temporary, and it became interesting to discover the time of duration of the magnetism. Mr Francis Watkins made some interesting experiments on this subject.† He found that when the *armature* or *keeper* is *removed* from the two poles of the magnet, it instantly loses all its magnetism when the electric current is cut off; but that if the *armature* is kept upon the poles, the soft iron magnet will retain its magnetism

* *Ann. de Chim.* vol. l. p. [illegible]; and Quetelet's *Corresp. Astronom. de Bruxelles.*

† *Phil. Trans.* 1833, part ii. p. 333-[illegible].

for a great length of time. Mr Watkins made a horse-shoe bar with a piece of soft iron eighteen inches in length and one inch in diameter, and he rendered it magnetic by winding round it in a single helix twenty feet of copper wire one-fifteenth of an inch thick. The ends of the copper helix being connected with a single pair of voltaic plates, the horse-shoe, when rendered magnetic by the current, supported 125 lbs. The voltaic action continuing, the weight was reduced to 56 lbs. and the voltaic plates removed; the weight was also carefully removed, so as not to displace the armature or keeper. The sustaining power of the horse-shoe was then tried every day, and at the end of ten days it sustained 56 lbs. as firmly as it did at first. Another horse-shoe bar charged with magnetism in November, was as powerful, and rather more so, in April, than it was at first. After a lapse of fifteen weeks it frequently supported 30 lbs. This soft iron magnet was tried at the Duke of Sussex's house on the 27th of April, *and, though nearly six months had elapsed since it received the magnetic virtue, it supported* 100 lbs.; but the instant that the *keeper* was separated from its poles, almost all the magnetism disappeared. When the keeper was again applied, there was not enough of magnetism even to support the keeper.

Mr Watkins made some interesting experiments on the lifting powers of soft iron magnets when plates of mica of different thickness were interposed between the poles and the keeper. The magnet was of the size and shape already stated, but Mr Watkins has not mentioned the successive thicknesses of the mica plates, nor does he state that they were of equal thickness. Had he mentioned the tints which each of them polarized, it would have been easy to compute their exact thicknesses. The following were his results :—

Number of Plates of Mica interposed.	Number of Pounds supported, besides the Keeper.
1	49
2	40
3	26
4	17
5	16
6	8
7	4½
8	2½
9	2
10	1½
11	1
12	0¾
13	0½
14	The keeper only.
15	0

When a piece of common *writing paper* was placed between the poles and the keeper, 28 lbs. were supported by the magnet.

SECT. XIV.—*Account of M. Aimé's method of making Permanent Artificial Magnets.*

This method, which has been recently published by M. Aimé,* is one equally simple and efficacious. It is founded on the facts described in the preceding section, and consists in holding a bar of red-hot steel with pincers between the two poles N S of a horse-shoe magnet rendered magnetic by an electrical current. The horse-shoe and the included bar, which should exactly fit the space between the poles, are then plunged in cold water, and kept there for a little time, depending on the size

* *Ann. de Chimie, vol. lvii. p. [illegible]*

of the real magnet, till the bar is thoroughly cold along its axis. In order to prevent the brass spiral wire that is curled round the horse-shoe bar from being wetted when the apparatus is under water, the extremities of the wire are enveloped in a piece of linen covered with mastic. The ends of the conducting wire should be soldered to the zinc and copper ends of the battery. M. Aimé employed a single wire for the spiral round the horse-shoe; but he observes that several may be united in a bundle, or a copper riband may be used covered with silk or varnish. In all the different trials that M. Aimé has made of this method, he has obtained satisfactory results.

SECT. XV.—*Account of the Experiments made by Coulomb and Kater, on the efficacy of the different methods of making Artificial magnets.*

Coulomb was the first person who examined experimentally the value of the different methods of making artificial magnets. The following is a brief abstract of his results.

1. *Wires of tempered steel, twelve inches long and one-twentieth of an inch in diameter.*

When rubbed at right angles on the pole of a single artificial magnet, it performed ten oscillations in seventy-four seconds.

When rubbed at right angles upon the poles of four united bar-Magnets, or magnetized by the methods of Duhamel and Æpinus, it performed the same number of oscillations in the same time. Hence *small* steel wires attain their maximum degree of magnetism equally well by all the different methods.

2. *A plate of annealed steel twelve inches long, one-third wide, and one forty-second of an inch thick.*

When rubbed at right angles on a single pole, it performed ten oscillations in seventy-seven seconds.

When rubbed on *two* united poles, ten oscillations in seventy-five seconds.

When rubbed on *ten* poles, ten oscillations in seventy-five seconds.

By the methods of Duhamel and Æpinus, ten oscillations in seventy-five seconds.

The effect of the different methods is now perceptible, the first being the worst.

3. *A plate of steel six and a half inches long, nine twenty-fifths wide and one forty-second thick.*

When rubbed on two poles, ten oscillations in fifty-one seconds.

Upon five poles, ten oscillations in forty-nine seconds.

Upon eight and ten poles, ten oscillations in forty-seven and a half seconds.

By Duhamel's and Æpinus's methods, ten oscillations in forty-seven and a half seconds.

4. *A plate eight inches long, fourteen twenty-fifths wide, and one twenty-fifth thick.*

When rubbed upon *one* pole, ten oscillations in seventy-three seconds.

Upon *four* poles, ten oscillations in sixty-two seconds.

Upon *ten* poles, ten oscillations in fifty-nine seconds.

At an inclination of 15° or 20°, on *two* poles, ten oscillations in fifty-three seconds.

At the same inclination on *four* and *ten* poles, ten oscillations in forty-nine seconds.

By Duhamel and Æpinus's methods, with *one* or more bars on each side, ten oscillations in forty-nine seconds.

5. *Bar of steel sixteen inches long, six tenths wide, and one-fifth thick.*

By magnetizing it on Æpinus's method, with *two* moveable bars rubbing on its surface, it performed ten oscillations in a hundred and ten seconds, and was found to be saturated. By Duhamel's method, it required moveable bundles of four bars each.

6. *Bar of steel sixteen inches long, one inch broad, and nine twenty-fifths thick.*

When magnetized by Æpinus's method, with bundles of four, or even ten bars, it performed ten oscillations in a hundred and fifty-three seconds.

But by Duhamel's method, with even *ten* bars, it only performed ten oscillations in a hundred and sixty-two seconds.

Hence the magnetic force communicated by the first method, was to that of the second as nine to eight.

Captain Kater made a series of interesting experiments on the directive force of needles, produced by different methods of magnetizing them. The needles which he used were right-angled parallelograms, five inches long, the one seven-tenths of an inch broad, and the other three and a half-tenths. The broadest was made thinner till it had the same weight as the other, which was 142 grains. The following table contains the result of the experiments.

	Directive Force. Small Needle.	Directive Force. Large Needle.
1. The magnets placed perpendicularly on the centre of the needle, and the needle rubbed from end to end on both sides......................	655	674
2. The same, but the magnets separated at top in the same way as at bottom....................................	595	580
3. The same as number one, but the distance of the lower ends of the magnets two and a half inches......	760	780
4. The magnets joined on the centre of the needle, and each moved towards the nearest pole, then lifted up and joined again, and so on......	993	1155
5. The magnets being joined on the centre of the needle, their lower ends were made to move to each pole, their upper ends remaining in contact................................	1025	1150
6. By Duhamel's method, the magnets inclined 45° to the needle; and moved from the centre to the poles..	1070	1170
7. The same, but the inclination of the magnets 20°........................	1085	1195
8. The same, but the inclination only 2° or 3°......................................	1160	1275
9. Magnets laid flat on the needle, and drawn from the centre to the end	1158	1261
10. Same as number eight but the separated ends of the magnets connected by an iron wire................	1145	1261

	Directive Force. Small Needle.	Directive Force. Large Needle.
11. Wire removed, and experiment number eight repeated...............	1260	1273
12. Needles hardened at a bright red, and then softened from the centre to within three-fourths of an inch of their extremities, and magnetized as number eight.........................	1815	1665

Captain Kater next ascertained the effect of length on the directive power of needles. He cut two needles of equal weight out of the same plate of steel, the one being *five* and the other *eight* inches long.

	Small Needle.	Large Needle.
13. Magnetized to saturation as in number eight...................................	1193	2275
14. Hardened and tempered beyond the blue, from the middle to within an inch of the poles.......................	1865	2277

Hence it follows, as Coulomb had ascertained, that the directive force of needles whose length exceeds five inches is probably as their lengths.*

* *Phil. Trans.* 1821, p. 104.

CHAPTER XI.

DESCRIPTION OF MAGNETICAL INSTRUMENTS.

The great importance and value of magnetical instruments, not only in the arts of navigation and surveying, but in the determination of the various and ever-changing phenomena of terrestrial magnetism, renders it necessary that we should enter with some detail into this branch of the subject. As a magnetic needle constitutes the principal, if not the essential part, of the greater number of magnetical instruments, we shall begin our observations with some details respecting the forms, description of steel, temper, and construction of magnetic needles.

Sect. I.—*On the best Form and Construction of Compass Needles.*

The most valuable experiments on this subject are those made by M. Coulomb and Captain Kater. Those of Captain Kater are particularly important.

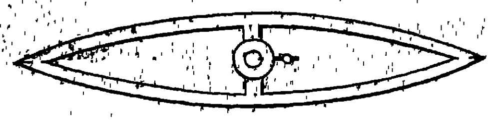
With regard to the material out of which the needle should be formed, Captain Kater found that needles of *shear steel* received a greater magnetic force than those of *blister steel* or *spur steel*, those of *cast iron* being much inferior to the others.

The next object of inquiry was to ascertain the form

of the needle which is best suited for receiving the greatest directive power. The forms which have been generally used are, the cylindric, the prismatic, that of a rhomb or a parallelogram, and that of a flat bar which tapers to its extremities like an arrow. According to the experiments of Coulomb, the form last mentioned, "*une lame taillée en flèche*," was the best, and was susceptible of a greater directive power than those which had the form of a parallelogram. He found that any expansion of the needles towards these poles was accompanied with a loss of power; and he drew the general conclusion, that in needles of the same form, their directive forces are proportional to their masses. Captain Kater likewise found that the directive force was little, if at all, influenced by the extent of its surface; but that it depended almost wholly on the mass of the needle when it was saturated with magnetism.

Captain Kater compared needles that had the form of a wide and a narrow rectangular parallelogram, and a small rhombus, a large rhombus, and a pierced rhombus, and he found that the form of the pierced rhombus is decidedly the best. A needle of this form (the sides of the rhombus are a little rounded in the figure,) as made by Dollond, is shewn in the annexed figure, the cross piece at the centre being made of brass or copper.

Fig. 82.

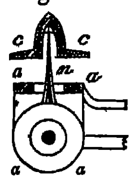


With regard to the best mode of hardening and tempering needles, Captain Kater found, that when a needle is considerably hardened throughout, its capacity for magnetism is diminished. He found that the needle was

susceptible of the greatest directive power when it was first hardened uniformly at a red heat, and then softened from the middle to within an inch of its extremities, by using a degree of heat which is just capable of making the blue colour, which is thus produced, to disappear. Captain Kater likewise found that the polishing of the needle, previous to its being touched, had no advantage; and that an increase of pressure of the touching magnets on the needle was sometimes injurious, and never useful.

When the needle is magnetized, it has a cap *cc* fitted into the opening in its centre, seen in fig. 82, and about one-fourth of an inch in diameter. This hollow cap is executed with great care, and is generally made of agate, (garnet is much better.) The interior curved surface, particularly the summit of it, requires the best workmanship. This summit rests on the pivot *n*, the point of which is wrought to an angle of from about 15° to 20°.* The use of the ring *a a* is to raise up the cap of the needle, and take it from the pivot, when it is not in use. The rod or handle *r* of this ring is continued to the outside of the compass-box, where it can be put in motion, so as to disengage the needle from its pivot, or replace it at pleasure.

Fig. 83.



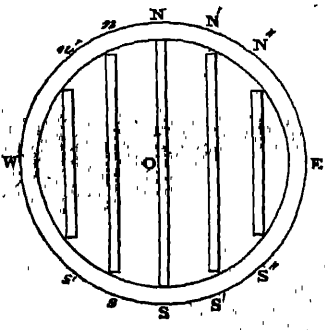
When a compass-needle is nicely balanced on a pivot, previous to its being magnetized, so as to traverse freely in a horizontal plane, it will no longer do so after it has been rendered magnetic. One of its ends will preponderate, in consequence of the tendency of the needle to dip, or place itself in a position parallel to the magnetic axis of the globe. In order to restore its equilibrium, therefore, it is necessary to add a small weight to one side of the

* Coulomb, *Mém. de l' Institut*, tom. iii. has shewn that this is the best angle for pivots.

needle, as shewn in fig. 82. The weight requisite for this purpose will increase with the dip, so that it may be necessary to slide the weight farther from the centre in going towards the magnetic poles, and *vice versa.*

As the needle of ordinary compasses is generally placed upon a card on which the various points of the compass are marked, in stormy weather it is necessary to give weight to the card, to preserve it steady during irregular motions of the vessel. Various contrivances have been adopted to remedy this evil. The usual method is to load the card with sealing-wax. Some place pieces of paper, like vanes, on the lower side of the card, to act against the air, and check the vibrations; while others have proposed to make the needle move in oil or other liquid, with the same view. The consequence of these contrivances is, that while the weight of the card, or its resistance to motion, is increased, the directive power of the needle remains the same, so that in getting rid of one evil another of greater magnitude is created. The mobility of the needle is diminished, and the steersman may mistake his course by trusting to the apparent steadiness of his compass.

Fig. 84.



The simplest remedy for this evil is to use a heavier needle, with a greater directive power, or by combining several needles together.

This idea also has been proposed by Professor Barlow, who constructs the card as shewn in the annexed figure, where N E S W is the card, and NS, N'S', N''S'', *n s*, *n's'*,

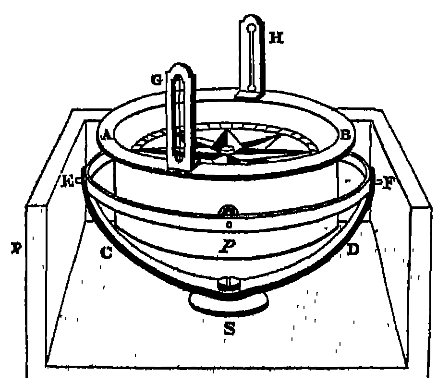
five parallel needles placed at equal distances. Mr Barlow has shewn that the directive force of this combination of needles is nearly *four* times greater than that of a single needle; but as the weight and friction on the pivot is increased nearly in the same proportion, no other advantage is gained but the proposed one (particularly requisite in boat compasses) of making the cards steady by their additional weight, while the relative directive power remains the same.

SECT. II.—*Description of the Common and Azimuth Compass.*

The common compass, whether it is called the *mariner's compass* or the *land compass*, serves only to point out the direction of the magnetic meridian, while *azimuth* compasses enable us to determine the angular distances of objects from the magnetic meridian.

The common compass consists of a needle fixed to a circular card, containing upon its surface the thirty-two

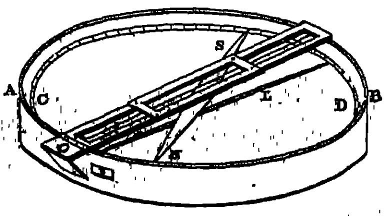
Fig. 85.



points of the compass. This card is balanced, as already described, upon a pivot fixed in the bottom of a circular box, and the top of the box is a plate of glass for protecting the needle from motions of the air. This compass-box, shewn at AB, fig. 85, is suspended within a larger box PQ, upon two concentric brass circles or gimbals, the outer circles being fixed by horizontal pivots both to the inner circle, which carries the compass-box, and likewise to the outer box, the two axes upon which the gimbals move being at right angles to each other. The effect of this construction is, that the compass-box AB will retain a horizontal position during the motions of the vessel.

The azimuth compass (fig. 85.) differs from the common compass principally in its being furnished with sights G, H, through which any object may be seen, and its angle with the magnetic meridian increased. For this purpose, the whole box is hung in detached gimbals CD, EF, which turn upon a stout vertical pin, seen above S′. In some instruments, the sights G H may be turned down by a joint over the glass when the compass is not in use, as shewn in the annexed figure; and in others they are connected by a brass bar, and may be taken from the compass when they are not wanted. In this compass, the card is divided on its rim into 360°; but the divisions are more frequently placed on a light metallic rim which it carries. The eye is applied to the sight H, which is a slip of brass containing a narrow slit. The other sight G, which is turned towards the object, contains an oblong aperture,

Fig. 86.



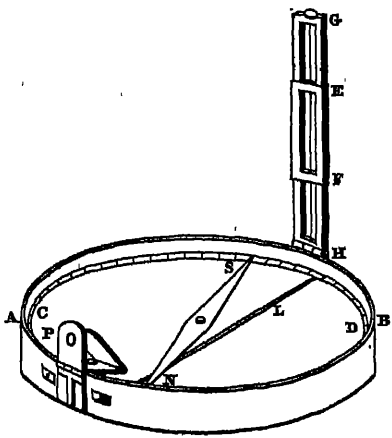
along the axis or middle of which is stretched a fine horse-hair or wire, which is made to coincide with or pass over the object or point whose angular distance or *azimuth* from the magnetic meridian is to be determined.

It is extremely difficult, when the ship is in motion, for the same person to take the bearing of the object and read off the angle; and various contrivances have been adopted to remedy this great defect. One of these is to have on one side of the compass-box a nut, which when pressed by the finger, pushes a lever against the card, and stops its motion, so as to allow the angle to be read off at leisure; but a false reading is often obtained with this contrivance.

SECT. III. — *Account of Captain Kater's Azimuth Compass.*

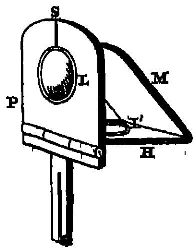
This ingenious compass may be regarded as an universal instrument, capable of being advantageously used both at sea and on land. It is represented in detail in figures 86, 87, and 88. In fig. 87, A B is a cylindric box made of brass, one inch deep, and covered with glass, and contains a card C D, five inches in diameter. The needle N S has an agate cap set in brass, and fixed in

Fig. 87.



its centre. The needle is fixed to a circular piece of talc, on the circumference of which is laid a narrow ring of card, which is graduated to half degrees on its outer margin. On the inner side of the box there is fixed a standing piece of ivory, which just projects over the outer margin of the graduated circumference of the card, and an index-line is engraved on the ivory as a point of departure for reading off the divisions on the card. A brass sight-frame GH is fixed by a hinge at H, on the opposite side of the box. It has the form of a parallelogram, and is five inches long. A frame EF, two inches long, slides up and down upon GH, and contains the segment of a glass cylinder, whose radius is five inches. When the solar rays fall upon this cylindrical bar, they are collected into foci, which form a line of light, which is thrown upon the index-line of the piece of ivory, and which may be seen at the same time as the divisions on the card. The frame GH, when folded down as shewn in fig. 86, acts upon a lever L, which raises the needle NS, and prevents it from traversing, by pressing it against the glass cover.

Fig. 88.



The sight-hole to which the eye applies itself is shewn at P, figs. 87 and 88. It is an inch from its hinge to its summit, but may be raised higher by means of grooves, in which a branch below the joint covers it, as seen in the figure. The upright plane P has a slit S terminating below in a circular aperture, which receives a convex lens. To this is fixed a horizontal plane H, having a lens in its centre; and above this, inclined to it at an angle of 45°, is placed a mirror M, by means of which and the lenses, an eye looking through the lens below S sees magnified the divisions on the card, distinct vision being produced by sliding the sight upwards or downwards.

In order to take the sun's azimuth, raise the object-

sight GH, and slide the cylindrical lens EF till its luminous line or focus falls upon the index. The eye-glass sight P is then to be moved up and down till it gives distinct vision of the index-line on the ivory. If the line of light is not narrow and well defined, incline the sight GH towards the compass till it is so, care being taken that the sight is perpendicular to the horizon, between the observer and the sun. When this is effected, incline the compass to the observer, so as to check the oscillations of the card, by bringing it in contact with the index and two pins fixed near it for the purpose. When the card is made steady by the repetition of this, taking care that the compass is inclined as much from the observer as will just free the card from the index, and that the line of light is bisected by the index-line, this lens will indicate on the card the azimuth of the sun required, which, when the correction on the card is applied to it, will give the true azimuth of the sun from the magnetic meridian; and by means of this element and the observed altitude, the variation of the needle may be obtained in the usual way.

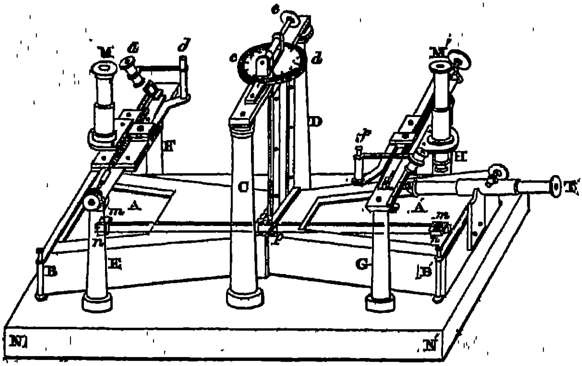
In using this compass for surveying, the cylindrical lens is slid to the top EG, and the hair or wire GH is then seen; and when this hair is made to bisect any object seen by direct vision, we have only to read off the azimuth of that object as seen on the card viewed by reflection.

By turning back the reflecting sight P round its hinge, the line of light may be viewed on the index, and the angle read off by direct vision,—a mode of observation which has its advantages.

SECT. IV. — *Account of the Variation Compass.*

The very complete instrument for measuring, with the nicest accuracy, the variation of the needle, and ascertaining its diurnal changes, which we have represented in the annexed figure, was constructed in Paris, we

Fig. 89.



believe by M. Gambey, and has been described by M. Pouillet. All the parts of it which are of metal are executed in copper. A table NN of white marble supports the pillars and case of the instrument. The columns C, D, are those by which the needle is suspended, and E, F, G, H, those which support the microscopes M, M′. The box of the needle is shewn at B, B′, and the needle itself AA′ is placed in the small copper ring *o p*, to which is fastened a wire or a number of silk threads without torsion, which suspend the needle, and which may be rolled round the small cylinder seen between *c* and *d*, and turned round by the milled head *e*. This wire is kept in the centre of the little graduated circle *cd*, by crossing at that centre a small triangular aperture. The wire is enclosed in a small cage of glass, which rises between the

two columns C, D, in order that the air may neither be agitated, nor penetrate into the box. By turning the milled head *e*, the needle A A′ may be raised or depressed at pleasure. Two moveable panes of glass shut up the apertures A A of the box, which are above the two ends of the needle. Upon each of the extremities of the needle there is firmly fixed a small plate of ivory *mn*, *m′n′*, bearing a very minutely divided scale, each of the divisions having the angular value of 15′ or 20′.

When the apparatus has been placed as nearly as possible in the plane of the magnetic meridian, and carefully levelled, we must see that the silk thread is without torsion; and by a few trials the microscopes M, M′, may be directed so as to see the zero or index of the ivory scales at the ends of the needle. It is then easy to observe the displacements which the needle experiences, either by counting the divisions which have passed under the wire of the microscope, or by following its motions by means of the screw by which the microscopes are moved. Small microscopes, one of which is shewn at *a*, and moveable round the rods *b*, *f*, are used to read off the position and course of each microscope M, M′ along the bar which carries it, and which regulates its lateral motion.

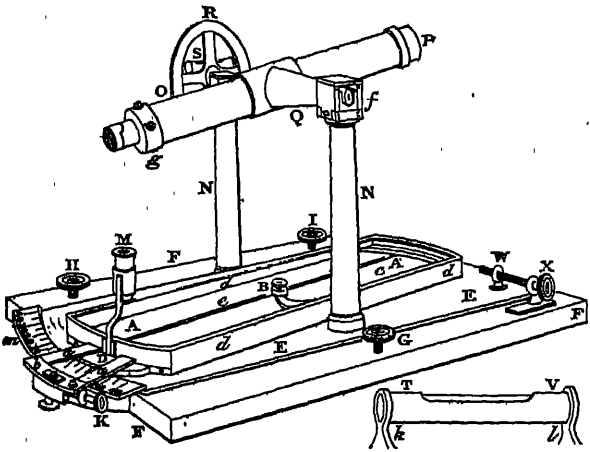
The telescope T is used for counting more conveniently, and consequently more correctly, the oscillations of the needle, when we wish to employ it for measuring the magnetic intensity. It carries before its object-glass a mirror, which reflects the vertical rays along the axis of the telescope.

Sect. V.—*Description of Colonel Beaufoy's Variation Transit.*

This instrument, which was employed by Colonel Beaufoy in the valuable series of magnetic observations which he made between the years 1813 and 1821, is

presented in perspective in the annexed figure, where EF is a mahogany board, which forms the support of the instrument, resting on three screws G, H, I, by which it

Fig. 90.



can be levelled. Above this is a flat plate of brass EE, fixed to the board by a centre pin, and resting upon three studs projecting from the board. It has a small horizontal motion round the centre pin, by means of the screw W and milled head X. The plate EE carries the graduated arc *m*, which is subdivided by the vernier D projecting from the box *ddd* containing the needle AA. This box moves on the common centre pin of the plate EE. In the plate which carries the vernier D is fixed the frame *aab*, which is furnished with a clamp-screw L to fasten it to the arc *m*, and a tangent screw K, by which the box *ddd* can be moved round its centre pin.

The centre pin of the box *dd* and plate EE terminates in a very fine pivot, on which the needle AA is suspended by means of an agate cap B, for diminishing the friction. The needle AA, which is a cylinder, is ten inches long

and one five-hundredth of an inch in diameter. It weighs sixty-five grains, and is terminated by two conical points; and it is furnished with the usual lever, &c. for lifting it from the pivot of suspension and lowering it again. There are within the box *dd*, and beneath the ends AA of the needle, two segments of brass, which have the centre lines drawn upon them; and these lines are brought to the points of the needle when the observation is made, by observing the coincidence through the double microscope M, which can be removed to the opposite end of the box.

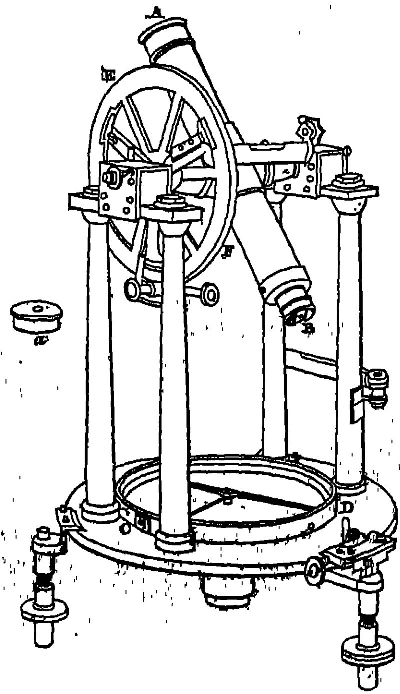
The transit telescope OP rests on two pillars NN, fixed on the brass plate EE, and having at their summits small boxes *f* for the reception of the Ys, in which the pivots of the conical axis Q of the telescope are supported. At the end of one of the pivots of this axis is fixed a small divided circle R, on an arm of which, provided with a level S, are placed the verniers for reading off the divisions. The eye-piece *h* admits a dark glass for solar observation, and the wires of the eye-piece are adjusted by screws at *g*. There is also a detached level TV, whose feet *k l* are placed in different directions upon the plate EE, for the purpose of levelling it. The use of the telescope is for finding the true meridian by means of the sun or stars, and the meridian should be indicated by fixed meridian marks.

When the instrument is properly levelled, and the telescope placed in the true meridian, the needle is allowed to settle, and the box *dd* is turned upon its centre till its mark comes near the point A of the needle. The clamp screw L is then fixed to the arc *m*, and the screw K, is turned till the coincidence of the index with the point of the needle is seen through the microscope M to be perfect. The vernier D will then shew the exact angle of variation, or the declination of the needle from the true meridian.

SECT. VI. — *Account of Dollond's Variation Transit.*

This instrument is shewn in the annexed figure. A brass pedestal CD, supported by three screws for adjusting it horizontally, forms the foundation of the four pillars which support the transit telescope AB, on the axis of which is fixed the graduated circle E, provided with all the usual contrivances for the accurate adjustment of the axis of the transit, and with microscopes for reading off the degrees. A cap or cover, seen separately at *a*, and containing a lens, is placed before the object-glass of the telescope, in order to convert it into a transit microscope, the focus of the lens being suited to the distance of the needle, seen between C and D, and the divisions of the graduated circle in the compass-box CD, the centre of the lens corresponding accurately with that of the object-glass. By this method

Fig. 91.

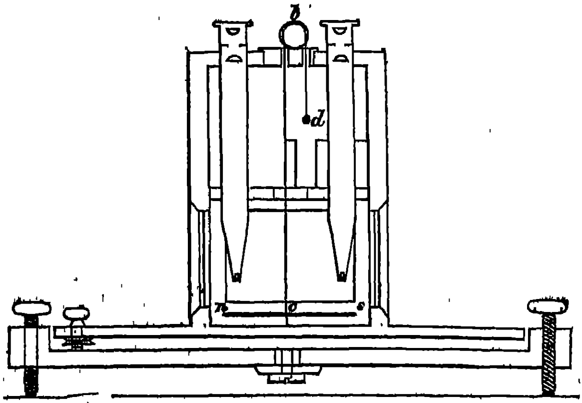


the correct place of the divisions, as well as of the needle, may be readily ascertained, and the extreme deviation, as well as its diurnal changes, accurately determined. This instrument may also be used as a theodolite, and employed for taking altitudes and equal altitudes.

Sect. VII. — *Description of Dollond's Diurnal Variation Instrument.*

This instrument is shewn in figs. 82, 92, 93, and 94.

Fig. 92.



It is made of mahogany and ivory, in order to avoid the attraction supposed to reside in all the metals. The needle *ns* is supported by the silk fibre *cbd* passing over a pulley at *b*, and counterpoised by a ball *d*. The two microscopes, seen on each side of *b*, have two cross wires, which, by means of the nut, seen in fig. 93, moving the frame to which the two verniers are attached, as well as the microscope, may be made to correspond with the index-lines on the ends of the needle *ns*, each end of the

Fig. 93.

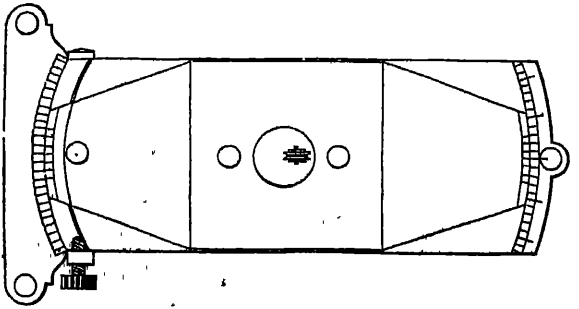


Fig. 94.

needle being observed, in order to correct the error arising from eccentricity. The mean of these two observations, as read off on the verniers, will give the angle of the diurnal variation. The needles used with the instrument are shewn in figs. 82. 94.; and there is also a piece of brass, of the same form and weight as the needles, in order to detect any twist in the suspending fibres of silk. This instrument might be used for measuring the magnetic intensity, by applying a contrivance for discharging the needle at the required angle. The diurnal part of this instrument was constructed for Captain Foster, who has published the observations which he made with it in the *Philosophical Transactions.*

SECT. VIII.—*Description of the Dipping Needle as constructed by Messers Gilberts.*

After the dip of the needle was observed, and its changes discovered, instruments of various forms were

contrived and used under the name of *dipping needles*, for measuring the dip or inclination of the needle to the horizon. One of the most recent and complete of these instruments, as constructed by Messrs W. & T. Gilbert, is shewn in fig. 95, in perspective. It consists of a brass

Fig. 95.

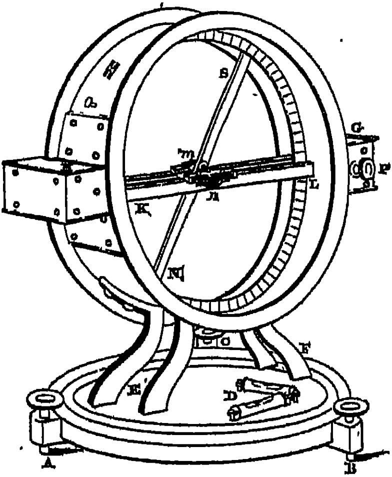


plate CAB, supported by three screws A, B, C, upon a flat board or stand. In the centre of this brass plate is another, ED, concentric with the former, and moveable round a centre pin like the moveable plate of a theodolite. This plate ED carries two levels at D for adjusting the plate horizontally. Four supports, shewn at E and F, carry the circular box HGP, or principal case of the dipping needle NS. Two equal brass bars, one of which is seen at KL, are firmly fixed across the case in a horizontal direction. Other two brass pieces *m*, *n* are fixed by screws to the centre of the bars K, L, and carry two finely polished planes of agate, on which the axis of the

needle NS rests, and upon which it turns freely. There is a contrivance inside the box G, and on the other side of K, L, not seen in the figure, by which the observer, by turning the milled head P, can lift, by means of Ys, the needle from the agate planes, or lower it upon them, at pleasure; the Ys being carefully adjusted, so as always to leave the axis of the needle on the same part of the agate planes, and in the centre of the divided circle. In this instrument the ends N S of the needle are graduated so as to act as a vernier scale for subdividing the degrees of the divided circle into 6′. A microscope is attached to the rim of the glass face, so as to be easily placed on any part of it, for the purpose of reading off the dip. In this instrument the length of the needle NS is six inches.

In order to obtain an accurate measure of the dip, several measures of it should be taken: *first*, with the face of the instrument to the east; *secondly*, with the face to the west; and the same observations repeated after the polarity of the needle has been inverted, or the north pole converted into a south pole, and the south into a north one. The mean of these four sets of observations will be the true dip required.

An account of Mitchell's dipping needle, as constructed by Nairne for the Board of Longitude, will be found in the *Phil. Trans.* for 1772, p. 476. The needles were a foot long, and the ends of the axes, which were made of gold alloyed with copper, rested on friction wheels four inches in diameter.

A complicated dipping-needle by Dr Lorimer, for determining the dip at sea, is described in the *Phil. Trans.* 1775, p. 79.

The dipping needle used by the Royal Society, and regarded as a model for instruments of this kind, is described by Mr Cavendish in the *Phil. Trans.* for 1776, p. [illegible]. The axis of the needle rested on agate planes,

and there was a contrivance, as in Gilbert's instrument above described, for raising and turning the needle upon the same part of the planes.

In one of M. Gambey's dipping needles, executed at Paris, and intended to be used at St Petersburg, the axis, instead of being cylindrical, is a knife edge, as in delicate balances. This edge is placed exactly in the centre of gravity of the whole compound needles, and is so fixed, that when the needle dips 71° (as at St Petersburg,) the edge rests perpendicularly on two agate plates. Such dipping needles, made for particular values of the dip, are admirably fitted for measuring minute variations of inclination, whether they be diurnal, menstrual, or annual.

SECT. IX.—*Account of Mr Scoresby's Magnetometer, for measuring the Dip of the Needle.*

This ingenious instrument consists of a horizontal table. a leaf, or part of which, made of brass, may be set by a screw and pinion at any angle to the horizon; and this leaf contains, near one of its edges, two rings, through which we can pass a bar of soft unmagnetic iron, so that its length is perpendicular to the axis or line round which the brass leaf moves. On the same side of the leaf, and concentric with the above axis, is a graduated circle divided into 360°, so that when the bar of iron is put into the rings of the brass leaf, the bar coincides, in every position of the leaf, with a radius of the divided circle; and it is therefore easy to measure the angle which the bar makes with the horizon, whatever be the position of the leaf on which it rests. A compass is placed on the fixed leaf of the table, which by means of levels may be adjusted to a horizontal position.

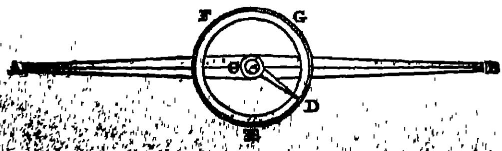
Now it has been ascertained by Mr Barlow, that when

a bar of iron is in the magnetic equator, it loses all its power of affecting the needle of a compass placed near it. Mr Scoresby therefore elevates the brass leaf of the table, and consequently the bar of iron, till it ceases to act on the needle, and the complement of the inclination of the bar, as measured by the graduated circle, is the dip required. This method is of course not equal in accuracy to that described above, or to the methods of Meyer and Professor Lloyd, explained in subsequent sections. It may be used, however, most advantageously in obtaining an approximate measure of the dip when more delicate instruments cannot be procured. See the *Edinburgh Transactions*, vol. ix. p. 247 ; and the *Edinburgh Philosophical Journal*, vol. ix. p. 41.

SECT. X.—*Account of Daniel Bernoulli's Dipping Needle.*

If A B is a needle, C its axis, a light graduated circle D E F G is fixed upon it, so as to have its centre coincident with C, and a light index D is fitted to the axis C,

Fig. 96.



so as to turn lightly upon it. Let the needle be magnetized previous to the putting on of the index D, and nicely balanced. The index will obviously destroy the equilibrium, and will always point perpendicularly to the horizon, if the needle has been properly balanced. As this degree of accuracy, however, cannot be expected, let the index D be set to different parts of the circle

E F G, and let the inclination taken by the needle before it is magnetized be noted down, corresponding to the different positions of the index. When the index points to 50°, for example, let the inclination of the needle be 46°. If we now observe that the needle is still inclined 46°, when the index is at 50°, after it is magnetized, then 46° is the true magnetic dip at that place, as the magnetism which it has received does not alter the position which it assumes from its gravity alone.

As it is easy to obtain a rude estimate of the dip at any place, let the index D be set accordingly, and if the needle does not now shew the estimated dip, the position of the index must be changed, and the inclination or dip of the needle again noted. Observe if this second position of the index, and the second measure of the dip, form a corresponding pair of numbers, such as have been written down. If they do, we have got the true dip; but if they do not, another position of the index must be tried. If the coincidence of this new pair of numbers is greater or less than that of the former pair, we shall learn whether the position of the index is to be altered in the same direction as before, or in an opposite one.

Dr Robison made several observations with a dipping needle of this construction, which was executed by a person totally unacquainted with the making of such instruments. He measured the dip with it at Cronstadt, at New York, and Scarborough, and the result never deviated more than 1½° from that obtained by the present dipping needles. He tried it also in a rough sea in Leith Roads, and he found it not inferior, either in accuracy or despatch, to the most elaborate instruments.

SECT. XI. — *Account of Mayer's Dipping Neddle as constructed for Captain Sabine.*

The method of observing the dip employed by the celebrated Tobias Mayer,* consists in separating the centres of motion and of gravity of the needle, and in deducing the true dip from the apparent dip thus obtained.

The needle executed for Captain Sabine on this principle was a parallelopiped $11\frac{1}{2}$ inches long, $\frac{4}{10}$ths broad, $\frac{1}{20}$th of an inch thick. The ends were rounded, and a line drawn on the face of the needle, through its centre to its extremities, for the purpose of an index. The needle turned upon a cylindrical axis of bell-metal, terminated by cylinders of the smallest diameter that could support the needle without bending. These small cylindrical ends rested upon agate planes. The needle was raised from or lowered to its support by Ys, which ensured that the same parts of the small cylinders rested on the agate planes in each observation.

A small steel screw was inserted in a female screw, tapped on the lower edge of the needle, in a direction perpendicular to the index line; and a small brass sphere was made to traverse on this screw, so that the centre of gravity of the needle, screw, and sphere, may be made to fall more or less below the axis of motion, and thus give the needle a momentum auxiliary to that of magnetism, in overcoming the inequalities of workmanship in the axis, or in the agate planes. Hence the position which the needle assumes, under these circumstances, is not that of the true dipping needle; but, by a sinple formula, the true dip may be deduced from four observations, when conducted in the following manner: —

* Göttingen Transactions, 1814.

1. Place the needle in the magnetic meridian, and observe the angle which it makes with the vertical. Call this angle M.

2. Reverse the position of the axis on its supports, so that the edge of the needle, which was uppermost in the preceding observation, is now lowermost, and observe again the angle which the needle makes with the vertical, and call this m. Let the poles of the needle be now reversed by means of a powerful magnet, and when it is replaced, make the same observations which have been already described, and call the angles thus obtained N n. Then calling the sum of the tangents of M and $m = A$; the difference of the same tangents $= a$; the sum of the tangents N $n = B$, and their difference $= b$. Then the dip A may be obtained from the following formula:—

$$\text{cotan.}\ \Delta = \tfrac{1}{2}\left(\frac{A \times b}{a + b} + \frac{a \times B}{a + b}\right).$$

In order to ensure the perfect horizontality of the agate planes, or of the axis of the needle which rests upon them, a spirit level attached to a circular brass plate, with adjustments to bring the level parallel to the plate, was placed upon the planes themselves. The errors of the level were shewn by placing the plate in various positions, and the errors of the planes, by turning the whole instrument on its horizontal centre.

If we observe the inclination of the dipping needle to the horizon in two different positions, so that the planes in which it moves are at right angles to one another, the true dip may be obtained from the formula:—

$$\text{cotang.}\ {}^2\Delta = \text{cotang.}\ {}^2\text{I} + \text{cotang.}\ {}^2\text{I}',$$

the inclination in the two rectangular azimuths being I, and I′. The dip may be thus very accurately obtained from the mean of a number of observations in different azimuths.

SECT. XII.—*Account of Professor Lloyd's method of observing the Dip and the Magnetic Intensity at the same time, and with the same Instrument.*

The ordinary dipping needle employed by Professor Lloyd, is supported on an axis which is supposed to pass accurately through its centre of gravity, and hence the position which it takes in the magnetic meridian is the direction of the magnetic force. If one of the arms of the needle, however, is loaded with a weight, the needle will assume a new position of equilibrium under the united influence of gravity and of terrestrial magnetism. By means of the inclination of the needle thus obtained, and the amount of the added weight, the dip of the needle and the magnetic intensity may be obtained by the following formulæ. Let $\mu\,\nu$ be the statical moments of two small weights attached in succession to the southern arm of the needle at fixed distances from its centre, and ζ be the inclination obtained with the weight μ and θ that obtained with ν. Then

$$\mu \cos. \zeta = \varphi\,\sigma \sin. (\delta - \zeta),$$
$$\nu \cos. \theta = \varphi\,\sigma \sin. (\delta - \theta);$$

the dip being denoted by δ, and the magnetic intensity by φ, and σ being a constant depending on the distribution of magnetism in the needle itself. Hence from the inclinations ζ and θ observed in the usual manner, and the ratio of the moments μ and ν, the dip and the relative magnetic intensity will be obtained at the several places of observation.

The most advantageous way of applying the preceding method Professor Lloyd considers to be this: He observes the position of the needle, *first*, when *unloaded*; and *secondly*, when loaded with a weight sufficient to

bring it into a position nearly perpendicular to the line of the dip.

Now, if $\mu = o$, we shall have $\zeta = \delta$, or the inclination first observed becomes equal to the dip, when there is no weight acting with or against the directive force. This condition, however, is never accurately fulfilled; for, from the imperfect coincidence of the centre of gravity of the needle with the axis, the weight of the needle itself is sufficient to deflect it from the true line of the dip. We must, therefore, regard ζ as the approximate value of the dip, and compute the correction for reducing it to its exact value.

For this purpose, put $\varrho = \frac{\mu}{\nu}$, and dividing the first of the above equations by the second, we have,

$$\frac{\cos.\ \zeta}{\varrho \cos.\ \theta} = \frac{\sin.\ (\delta - \zeta)}{\sin.\ (\delta - \theta)}.$$

Then, if we make $\delta = \zeta + \epsilon$, the second term of the preceding equation becomes $\frac{\sin.\ \epsilon}{\sin.\ \zeta - \theta}$ *q.p.* since ϵ is a very small quantity, and we have

$$\sin.\ \epsilon = \varrho \frac{\cos.\ \zeta}{\cos.\ \theta} \sin.\ (\zeta - \theta).$$

Hence we may find the dip by means of these two equations, and we may deduce the correction for an imperfect balance of the needle from the two observed inclinations, without reversing the poles of the needle, as in the method of Tobias Mayer.

The value of the co-efficient ϱ in the last equation is given in the following formula:—

$$\varrho = \frac{\cos.\ \theta \sin.\ (\delta - \zeta)}{\cos.\ \zeta \sin.\ (\delta - \theta)}.$$

The magnetic intensity at different stations may be obtained from the dip by the second equation.

The quantity σ being the statical amount of the free

magnetism of the needle, or the *magnetic moment*, must vary with the temperature. If τ is the temperature of observation, τ' a certain standard temperature, and σ' the corresponding value of σ, then, if we suppose the changes of σ to be proportional to those of τ, we have

$$\sigma = \sigma' (1 - \alpha) (\tau - \tau'),$$

α being a constant to be determined by observation, and which Professor Lloyd found to be 0·00016.

The quantity ν is the sum (or difference) of the moments of the weight of the needle, and of the added weight, and its value is

$$\nu = \nu' (1 - e \cos. 2\lambda),$$

where ν' is the value of ν corresponding to the latitude of 45°, λ the latitude of the place, and e a constant whose value is 0·002588. Hence we obtain for the magnetic intensity

$$\varphi = \frac{\nu' \cos. \theta}{\sigma' \sin. (\delta - \theta)} + \frac{1 - e \cos. 2\lambda}{1 - \alpha (\tau - \tau')},$$

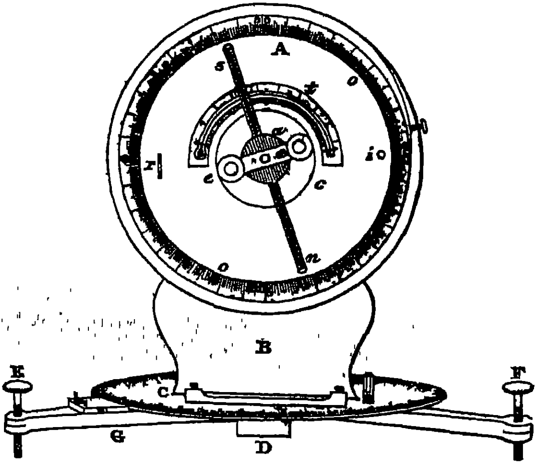
an expression peculiarly adapted for logarithmic computation. See *Memoirs of the Royal Irish Academy*, 1835.

Sect. XIII.—*Description of Mr Fox's Dipping Needle Deflector, for measuring the Variation and Dip of the Needle, and the Magnetic Intensity.*

This ingenious instrument, for ascertaining the variation, dip, and intensity of terrestrial magnetism, has been pretty extensively used by Mr Fox in different parts of the united kingdom. The results have been published, both in a table, and in a chart, in an extract from the *Report of the Royal Cornwall Polytechnic Society for* 1835.

The deflector is shewn in the annexed figures, where A is a cylindrical box of brass, fixed vertically in the stem B and horizontal plate C, all of which can be turned

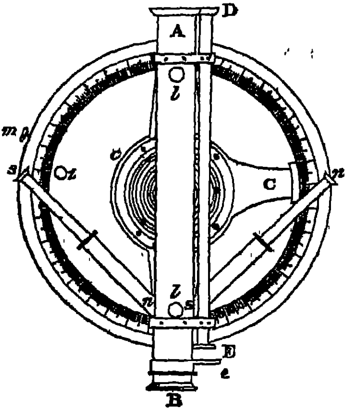
Fig. 97.



round on their common axis D, ground into the centre of a tripod, two of whose legs are shewn at E and F. The graduated circle in C is subdivided by a vernier and tangent screw G, levels being placed at right angles to each other for adjustment. The needle *n s*, with a small grooved wheel *a* fixed on its axis, is supported by the concentric disc *c*, and a bracket *e* attached to the disc, the axis of the needle moving in jewelled holes. The disc *c* is accurately fixed into the back of the box, and may be turned round with the bracket on its axis by means of knobs on its back, shewn in the annexed figure. By this contrivance the bracket may be moved round to any convenient position, so as not to interfere with the dip of the needle in any latitude.

The socket *v*, fixed to a brass spring, when pressed forward by the screw *m*, is intended to confine the ends of the needle when not in use. There are two parallel graduated rings, one of which is a little within the outer

Fig. 98.



surface of the dipping needle, as shewn at *oo*, fig. 97; the other ring, supposed to be removed in the figure, is immediately under the glass, its object being to direct the sight, and enable the observer to subdivide the degrees on the inner circle. A thermometer is shewn at *t*. The back of the dipping needle box is shewn in fig. 98; the back of the moveable central disc is grooved, and a brass rod is drawn over the grooved surface in order to make the needle vibrate.

A telescope A B, having cross wires, is capable of being moved in a vertical plane in any direction, by means of a concentric ring *c*, grooved into another concentric ring attached to the back of the instrument, and furnished with a flanch. An arm C, at right angles to the telescope, has a vernier for subdividing the graduated circle on the back of the box. A small tube D E for solar observations, is fixed parallel to the telescope. This tube has a convex glass at D, whose focal length is rather longer than the tube; and there is a plane glass at E, with a small circular spot on it, which forms, with

the concentrated light of the magnifying glass, a distinct annular image on an ivory or plaster of Paris surface at *e*. Magnetized steel bars are placed in the brass tubes *n s*, *s n*. Their position, as well as that of the telescope, when not in use, is shewn in fig. 99, the *n* and *s* poles of the magnet being brought near the *s* and *n* poles of the dipping needle in the box, in order to induce a uniformity in their relative states of magnetic intensity. Holes *l l* are made in the tube of the telescope, to allow the magnets to be passed through it, and screwed into the arms which hold the telescope. This is shewn at *n* and *s*, fig. 98, which represents a side view of the box, and the places of the magnet when employed for ascertaining the intensity. Screws for fixing the ring and glass cover over the face of the instrument, are shewn at *a a*. Fig. 100. represents a grooved wheel fixed in the axis of the needle *a*, with a fine silk thread, having hooks at each end, passing over the wheel in the grooves.

Fig. 99.

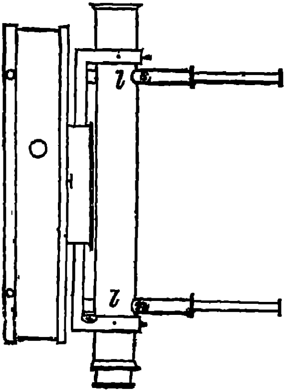


Fig. 100.

The following rules for using the instrument are given by Mr Fox :—

To observe the magnetic variation.—Ascertain the true meridian by any of the usual methods ; the small tube being used for solar observations, and the telescope for observations at night. Note the angle cut by the nonius on the circular plate C. If the plate be turned round 90° from that point, the

face of the instrument, or rather the plane in which the needle moves, being parallel to that of the tubes, will be at right angles to the plane of the true meridian. The deflecting tubes *n s* having been removed from the back, turn the instrument round *gradually*, so that the needle may become *perfectly vertical* after vibration; friction having been employed several times at the back of the central disc. Fig. 98.

The face of the instrument will then be at right angles to the plane of the magnetic meridian; and the angle described on the circular plate will give the variation from the true meridian. The face of the instrument, however, should always be turned round to the opposite quarter, till the needle again becomes vertical, which will either confirm or correct the preceding experiment, by taking half the difference between the two observations.

To ascertain the dip.—The face of the instrument having been made to coincide with the *plane* of the magnetic meridian, suppose it to be at first turned toward the east; note the exact dip at *both* ends of the needle after vibration, as before described, (this precaution should, in every case, be carefully attended to, and repeated several times;) then turn the face of it toward the west, placing it in the same plane, and observe and note as before; the mean of these observations will give the dip.

To correct the observed dip.—The instrument being still in the magnetic plane, and fixed in that position by means of the lever or clamp, connected with the nonius screw on one of the deflectors *n s* at right angles to the tube, as shewn in fig. 99, so as to repel or deflect the end of the needle which is nearest to it; then, if the observed dip was 69° 45′, move the deflector a certain number of degrees from 69° 45′, as shewn by the nonius *c*, say 50° to the right of the dip, when the needle will

be repelled in the opposite direction; suppose the mean angle at *both* poles of the needle, after frequent vibrations, to be . . . . . . 54° 33′
then move the tube 50° to the left of the dip, when the needle will be repelled in the contrary direction; suppose it to stand at . . 84° 47′

Mean, . 69° 40′

If the face of the instrument, whilst making these observations, should be towards the east, turn it round towards the west, adjusting it in the same plane, and repeat the observation; if the mean result should be . 69° 46′
the mean or corrected dip will be . . 69° 43′

Similar observations may be multiplied at pleasure, by varying the angles of the deflector from the observed dip; and by thus taking the mean of many observations, the true dip may be obtained with a great degree of precision.

To find the relative intensity of the terrestrial magnetism.—The instrument being still in the plane of the magnetic meridian, screw the deflectors (or one of them) into the arms at the back of the instrument, as shewn in fig. 98, and cause the latter to coincide with the direction of the dip, when the needle will be repelled from it; mark the angle to which the needle points at both ends, (after repeated vibrations, as before described,) then cause the needle to swing back to the other side of the dip, (one of the deflectors being temporarily removed for this purpose,) and note its place as before: half the sum of the angles to which the needle is thus deflected (or rather of their sines) will represent the relative force of the terrestrial magnetism, at different places, on a needle thus circumstanced. It is desirable that the observations should be made with the face of the instrument turned towards the east as well as towards the west; and likewise only one deflector may be used as well as both of

them, in order to vary and multiply the observations for the purpose of correction.

If the angle of deflection at a second place of observation should be greater or less than at the first, the force of the earth's magnetism will be inferior or superior to the latter, as represented by the different angles.

The amount of any such difference may, when required, be represented by weights. For this purpose, the glass which protects the face of the instrument should be removed, and the silk thread placed on the grooved wheel, as shewn in fig. 100. The minute weights required to be suspended to one of the hooks, in order to bring the needle to some given angle from the actual dip, will indicate the relative magnetic intensity at different stations. Suppose, for example, that at a given place, the observed dip is 70°, and that at a second place, in a lower latitude, it is 45°; adjust the deflectors as before described, so as to coincide with the dip of the needle at the place of observation, whatever it may be. Assume that the needle is repelled 70° from the dip of 70° at the first station, and 80° from the dip of 45° at the second station; it will shew that the terrestrial magnetic intensity is greater at the former than at the latter. The weights required to be suspended to one of the hooks, in order to bring the needle to its original position of 70° from the dip (if that be taken as the standard) will indicate the difference of intensity. Thus, for instance, if five-tenths of a grain be required to bring the needle from the angular distance of 80° to that of 70° from the dip at the second station, this weight will indicate the *difference* of the magnetic intensity of the earth at the *two* stations, acting on the needle in question, when at an angle of 70° from the natural dip.

The ratio of this difference to the whole force of the terrestrial magnetism so acting may be ascertained by moving the deflectors to the angle of 70° from the dip,

(because the needle is assumed to have been deflected to this angle at the first station ;) the needle will then be repelled to the opposite side of the dip, and the weight required to counteract the deflection sufficiently to bring it back to the dip will represent the whole influence of the earth's magnetism at the first station on the needle, whilst at the angle of 70° from the dip. This will be evident, when it is considered that the angle between the needle and deflectors is in both instances the same; it being coerced, contrary to the repelling force of the deflectors, in one case by the earth's magnetism, and in the other by the weights, to the *dip or line of quiescence*, the earth's magnetic force acting on the needle so deflected, and the weights will therefore be equal to each other. If 3·34 grains be the weights required, and five-tenths of a grain equal to the difference between the two stations, the terrestrial magnetic intensity will be in the ratio of 3·34 — ·5 = 2·84 at the second station, to 3·34 at the first station.

From the observations which have been already made with the dipping needle deflector, furnished with a needle less than six inches long, there is good reason to believe that it will clearly indicate a difference of intensity at places situated at less than one half a degree of latitude from each other.

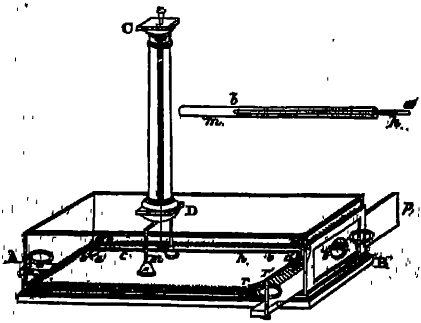
Observations on the magnetic intensity and dip may likewise be made *without the deflectors*, by means of the weights only, suspended from the silk thread, shewn in fig. 100. This method is too obvious to require a minute description, the weights in this case being used to produce deflection from the dip at any place, instead of the magnetic deflectors; the weights required to cause a given amount of deflection being taken as the relative measure of the magnetic intensity at the place of observation. Thus, in the case before supposed, 3·34 grains would produce a mean deflection of 70° from the dip at

the first station, and only 2·84 grains would do so at the second station.

SECT. XIV.—*Account of Lebaillif's Sideroscope.*

The object of this instrument, proposed by M. Lebaillif, is to detect minute degrees of magnetism, by means of a very delicate combination of small magnetic needles. This apparatus, which he calls a *sideroscope*, is shewn in the annexed figure, where A B C D represents the body

Fig. 101.



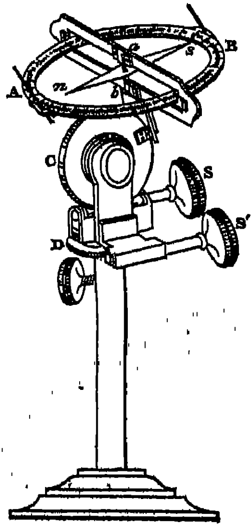
of the instrument. The other parts consist of three sewing needles magnetized to saturation, and a tube of straw, twelve or fifteen inches long. One of these needles, *a b*, is slid into the tube *m h*, and the others *a′ b′ a″ b″* are placed across the straw, so that their dissimilar poles correspond. The straw thus fitted up is placed upon a small stirrup of paper, which is suspended by a silk fibre fixed at the top C of the vertical tube of glass or wood C D. The portion *m h* of the tube of straw is the longest, and it is beneath its extremity *m* that there is placed on the bottom of the cage or box A B, an arch *r r r*, divided into degrees and half degrees. The portion *m e* has no directive force, as the action of the

earth is neutralized in the two opposed needles $a'b'$, $a''b''$. But the portion mh has a directive force depending on the magnetism of the needle ab, on its length, and on its distance from the point of suspension. The cage has a small sliding door, tp, which shuts up the apparatus; and when an experiment is made, the aperture at t is brought opposite the extremity a of the needle.

M. Lebaillif has proved that almost all bodies exercise some action on the needle, and that *antimony* and *bismuth* always exert upon it a repulsive force. M. Pouillet, from whose work we have taken this description of the instrument, is of opinion that the movements of the needle may be often owing to atoms of iron; and that we must not take it for granted that, in these phenomena, the magnetic force is the only one which is acting.

Sect. XV.—*Description of the Astatic Needle.*

Fig. 102.



This instrument, described by M. Pouillet, is called the *astatic needle*, because it is withdrawn from the action of the earth's magnetism, and has no longer the statical position in which it is in equilibrio with the influence of this force. The construction of the astatic needle is founded on the principle that a body which is moveable round an axis cannot receive any motion from a force which acts parallel to this axis.

The astatic needle is represented in the annexed figure, where ns is a magnetic needle, moveable round the axis ab. If this axis is placed in the direction

in which terrestrial magnetism acts, the needle will rest in any position. This effect is easily produced by two motions perpendicular to each other, one of which is obtained by the milled head S′, which, by an endless screw on its axis, works in the teeth of the wheel C, and the other by the milled head S′ and the wheel D, the graduated circle AB shewing the positions of the needle.

Another contrivance for an astatic needle is shewn in the annexed figure (103,) where two needles A B, A′ B′, perfectly alike in their form and magnetic intensity, are turned in opposite directions, and placed upon the same axis perpendicular to their length.

A more perfect compensation in the action of two needles is shewn in fig. 104, where A′B, A′B, are the two

Fig. 103.

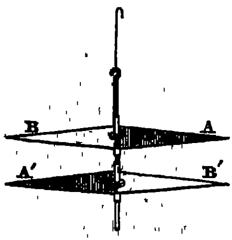
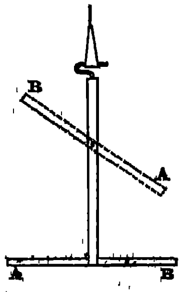


Fig. 104.



needles, the one horizontal and the other inclined to the horizon. It is obvious that the directive force of the latter will augment with its inclination, and it is therefore easy to make the directive forces of each perfectly equal and opposite, by varying the inclination of the uppermost one. These two contrivances we owe to M. Pouillet.

A magnetic needle may also be rendered astatic by neutralizing the action of the earth, by means of an equal and opposite magnetic action. For this purpose we have only to place a powerful bar-magnet at a considerable distance from the needle, so that it may act upon it as

powerfully as the earth does. It should be placed in the magnetic meridian, parallel to the direction which the needle takes when it is in equilibrio, the pole of the bar which repels that of the needle being placed nearest it. When the bar is placed near the needle, it will cause it to wheel round, in consequence of its action exceeding that of the earth. At a very great distance, on the contrary, the earth's action will predominate, and draw the needle into the magnetic meridian; but an intermediate distance will be found in which the two actions exactly balance or compensate each other, and render the needle astatic.*

SECT. XVI. — *Account of Barlow's Correcting Plate or Magnetic Compensator for neutralizing the effect of Local Attraction on the Ship's Compass.*

As every ship contains large fixed masses of iron, besides moveable iron guns, anchors, cables, and iron utensils of various kinds, it is obvious, from the principles and experiments already detailed (see Chapter V. &c.) that these masses, rendered temporarily magnetic by the action of the earth, must produce derangements in the magnetic needles of the compasses on board. These derangements amount sometimes to 15° or 20°, and have exposed navigators to the most imminent perils. Mr Wales, the astronomer to Captain Cook's expedition of discovery, first discovered the fact that such a deviation existed; but he does not seem to have suspected its cause. Mr Downie, master of his majesty's ship Glory, was the first person who pointed out the true origin of the deviation. "I am convinced," says he, "that the quantity and vicinity of iron in most ships have an effect

* See Pouillet's *Élémens de Physique*, livre iii. chap. ii.

in attracting the needle; for it is found by experience that the needle will not always point in the same direction when placed in different parts of the ship. Also it is rarely found that two ships, steering in the same course by their respective compasses, will go exactly parallel to each other, yet these compasses, when compared on board the same ship, will agree exactly."*

In his survey of the coast of New Holland, in 1801 and 1802, Captain Flinders observed great differences in the direction of the needle, which arose only from changes in the direction of the ship's head, the direction being westerly when the ship's head was to the east, and *vice versa*. Hence he concludes, "that the attractive powers of the different bodies in the ship which are capable of affecting the compass, are collected into something like a focal point or centre of gravity, and that this point is nearly in the centre of the ship, where the shot are deposited, for here the greatest quantity of iron is collected together."† He likewise supposes that this magnetic centre is of the same name as the pole of the hemisphere where the ship is, and, consequently, that in New South Wales the south end of the needle would be attracted by it, and the north end repelled; and from this hypothesis he concludes that the phenomena must be exactly the reverse in the northern hemisphere.

The Admiralty ordered a course of experiments to be made on this important subject, but though they established the truth of Captain Flinder's views, the subject was not farther prosecuted. The public attention, however, was again called to it by Mr Bain, who, in an excellent treatise on the variation of the compass, pointed out the fatal consequences which might result from this great source of uncertainty in the indications of the needle. The observations of Captain Ross, Parry, and

* Walker *on Magnetism*, 1794, cited by Prof. Barlow.

† *Phil. Trans.* 1805, p. 186.

Sabine threw additional light upon the subject; but it is to Professor Barlow alone that we owe a series of brilliant experiments, which terminated in his invention of the neutralizing plate, for correcting in a perfect manner this source of error in the compass.

In order to give an idea of the magnitude of this error, Professor Barlow, has published the following table of deviations actually observed: —

Ship.	Place.	Observers.	Deviation in the compass.
Conway	Portsmouth	Captain Hill	4° 32′
Leven	North fleet	Captain Owen	6 7
Barracouta	Ditto	Captain Cuttfield	14 30
Hecla	Ditto	Captain Parry	7 27
Fury	Ditto	Captain Hoppner	6 22
Griper	Nore	Captain Clavering	13 36
Adventurer	Plymouth	Captain King	7 48
Gloucester	Channel	Captain Stuart	9 30

The instrument employed by Professor Barlow is shewn in the annexed figures, where T is a rod of copper an inch and a half in diameter, and FF′ two plates of iron about twelve or thirteen inches in diameter, and of

Fig. 105.

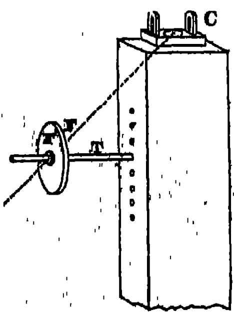
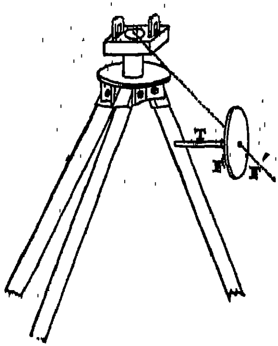


Fig. 106.



such a thickness that a square foot of it will weigh about 3 lbs. avoirdupois. These plates are separated by a circular sheet of card, and pressed against each other at their centre by a screw on the end of the rod T, and at their margins by three small screws of iron. The compass C is placed on the tip of a wooden box B, and the corrector T is placed in one of the holes in the side of the box.

The adjustment of the plate is made when the ship is lying in a calm bay near the shore. An observer with a needle and theodolite is placed at some distance from the shore, from which he can perceive the ship while it is turning its head in different directions. The compass on board the ship is under the management of another observer with the same apparatus. At a signal given the observer determines the angle which his own needle makes with the axis of the telescopes, (one being directed to the other,) which is called the central line. But as the needle on shore experiences no disturbing action, it is evident that if the needle on ship-board also experience none, the two needles will be parallel, and will form the same angle with the central line. Hence the difference between these two angles when they are not the same is that which is produced by the magnetic action of the iron in the vessel from its compass needle at the instant of observation. Let the vessel be now made to turn round completely, and let a new observation be made at every azimuth of ten or twelve degrees; we shall then have the value of the deviation produced in all positions of the ship's head upon the compass needle. When this is done, the observer on shore takes away his compass and replaces it with that of the ship, which he sets on the wooden cage shewn in fig. 105, having different holes for receiving the axis T of the plate FF. As the box B is turned round its axis, it carries along with it the compensator F F′, which will affect the

needle of the compass C differently in different azimuths, and by a few trials it may be adjusted, by means of the holes of its axis T, to produce the very same deviations in the compass as was produced upon it when in the ship by the action of its iron. When it is done, the position of the centres of the plate FF′ with regard to the needle is completely marked, and when it is taken on board the ship and placed in its proper position, the compensator is adjusted on the stand which carries the compass, as shewn in fig. 106, so as to have exactly the same relative position as it had in the box B.

Now, since the compensator produces the same effect as the iron on shipboard does, the deviation will be *doubled* in place of being corrected; but this furnishes the means of making the correction. If the variation is found to be 36° W. by the compass *without the compensator*, and afterwards 40° with the compensator, the difference $40° - 36° = 4°$ shews that the compensator augments the variation 4°, and the iron on board the vessel as much. Hence the true variation will be $36° - 4 = 32°$, or $40 - 4 - 4 = 32°$. If the observations with the compensator had given a less result than without it, this would have shewn that the action of the iron had diminished the declination, and the difference of the two observations must have been added to the first, to have the true declination.

CHAPTER XII.

THEORIES OF MAGNETISM.

The phenomena of magnetism, like those of every other branch of physics, have afforded the groundwork of many absurd and wild theories. The hypotheses of Descartes and Euler, which created in the interior of magnetic bodies canals and valves to admit or obstruct subtile matter, to the agency of which they ascribed the attractive or directive power of magnets, are too ridiculous to deserve any notice in the present state of the science.

M. Æpinus of St Petersburg was the first philosopher who discovered a rational hypothesis, which explained nearly all the phenomena of magnetism. This hypothesis of one fluid, however, of which we have already given a short account in our history of the science, was found insufficient for explaining the phenomena which are exhibited in the division and fracture of magnets; and though it was susceptible of a correction, which consisted in considering a magnet as composed of small particles of iron, each of which has individually the properties of a separate magnet, yet it did not afford a complete explanation of all the magnetic phenomena.

The hypothesis of two fluids, which was first proposed by Wilcke and Brugmann, was established by M. Coulomb, and has recently been perfected by the masterly investigations of M. Poisson, who has not only constructed mathematical formulæ which enables us to calculate all the minutest details of the phenomena, but has enabled us to comprehend physically how all the phenomena

have been produced. The general equations at which he has arrived have not yet, in every case, been resolved; but the particular conditions under which the integrations are possible, have already, as we have stated, exhibited the most happy coincidence with experiment.

The hypothesis of two fluids, supposes that they reside in each particle of iron; that they are neutral and inert when combined, as in soft iron; and that, when they are decomposed, the particles of the *austral* fluid attract those of the *boreal* fluid, and *vice versa* while they each repel one another.

In order to account for the phenomena of the division and fracture of magnets, it is necessary to suppose, that when the united fluids are decomposed, the fluids undergo displacement only to an insensible distance. The minute portions of a magnetic body within which the motions and displacements resulting from decomposition take place, or in which magnetism exists, are called the *magnetic elements* of that body, and the small intermediate spaces where magnetism is not found, the *non-magnetic* elements. It is impossible to determine whether the *magnetic elements* are the intervals which separate the ultimate atoms of material bodies, or if they are the atoms themselves; nor can we ascertain whether they are the intervals between an aggregate number of atoms, or of a secondary molecule, or the aggregate members themselves. The theory regards the sum of the magnetic elements and of the non-magnetic elements as forming the apparent volume of a body. The ratio of these two sums may change with the nature and temperature of the body; and these changes exercise a powerful influence over the distribution and intensity of magnetism.

The quantity of each fluid in every magnetic element is unlimited in reference to our powers of separating them, as the united fluids can never be completely decomposed. The force which prevents this decomposition, and also

the recombination of the fluids, is called the *coercive force*, and, like that of friction, it cannot be completely overcome. In soft iron, this coercive force is extremely feeble. In the natural loadstone, and in steel, it is very powerful, varying in intensity in different kinds of this metal.

One of the most important consequences of the theory of Poisson is, that a magnetic needle, whose size is so small that it exerts no sensible action on an iron sphere within which it is placed, will intercept the magnetic influence of the earth, and of all magnetic bodies without the sphere; and, in like manner, such a sphere will intercept the action of a magnet within it on all bodies without t. Another interesting consequence of the theory is, that in a hollow iron sphere, magnetized by the influence of the earth, or of any magnetic force, the origin of which is at such a great distance that it may be considered as acting in parallel lines, although the magnetism is not confined to the surface of the sphere, and though its intensity may be determined for any particular point of the solid mass of the shell, yet it is determined only by the radius of the external surface, and the coordinates of the point upon which the forces act. When this point is very remote from the centre of the sphere compared with its diameter, each of the three forces is nearly in the direct ratio of the cube of the radius, and in the inverse one of the cube of the distance.

M. Poisson has likewise applied his powerful mind to the explanation of the singular phenomena of magnetism produced by rotation. To the suppositions which his theory makes in order to explain the phenomena of magnetism induced by influence, he adds another, namely, that all bodies exert upon the *boreal* and *austral* fluids a species of action analogous to the resistance of media, which action has the effect of retarding the motion of the two fluids in the interior of the magnetic elements;

and he conceives that it is this species of resistance, and not the coercive force, which has an influence over the magnetic phenomena of revolving bodies. Hence, if we bring a magnet near any body on which the coercive force is insensible, and in which the magnetic elements are in any proportion, the decomposition of the neutral fluid will begin immediately, and will continue till the action of the free fluid is in equilibrio with the external force, which will certainly take place if this force is constant in magnitude and direction. But if it varies continually, or if the loadstone changes its position, the two fluids, in place of arriving at a permanent state, will move in each element with velocities dependent, other things being equal, on the resistance which the substance of the body opposes to them.

It is needless to enter into any farther details respecting this very ingenious theory, as the recent discoveries of Mr Faraday respecting electro-magnetic induction have enabled him to give a most satisfactory explanation of the diversified phenomena of magnetism in motion.

FINIS.

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